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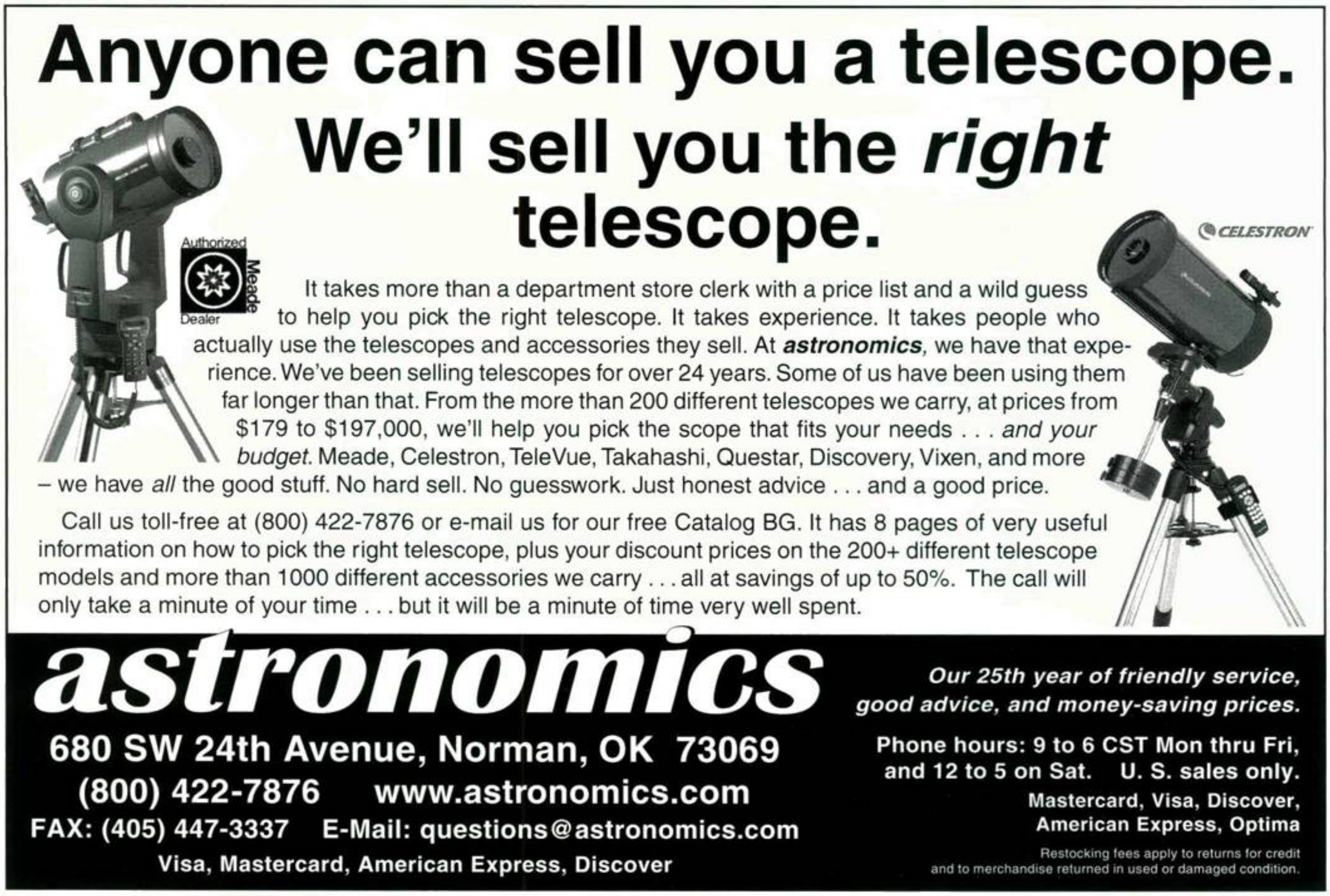

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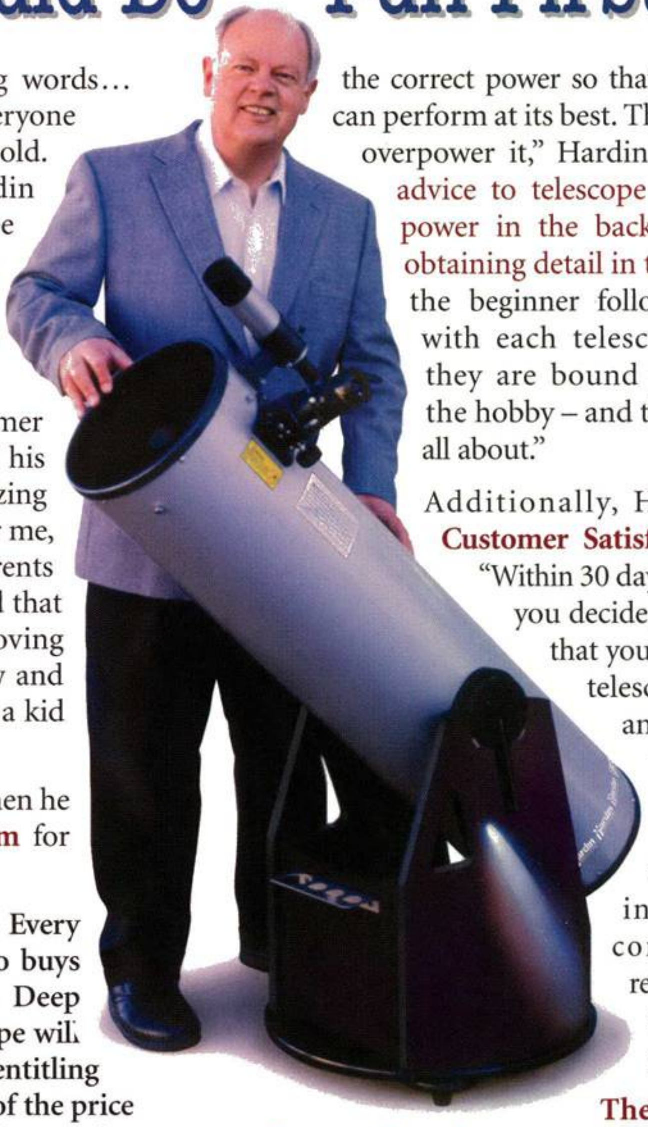

Larry Hardin is known for not mincing words… especially when it comes to telescopes. "Everyone should have a telescope…even a five-year-old. You can never start too young," Hardin emphasizes. "The problem is, most telescope makers scare off beginners by emphasizing the science more than the fun. Amateur astronomy should be fun first; the science will come as the enthusiasm grows."

Larry Hardin has been an amateur astronomer and professional telescope maker most of his life. "When I was a kid, I remember agonizing over which scope would be my next one. For me, it was a huge investment requiring my parents to pitch in," he explains. "Then I discovered that telescope makers were constantly improving their models and I always wanted the new and larger versions. It was like that when I was a kid … and it's like that today."

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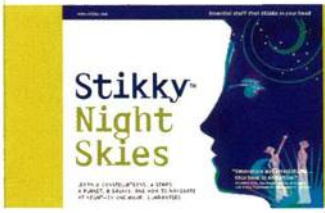

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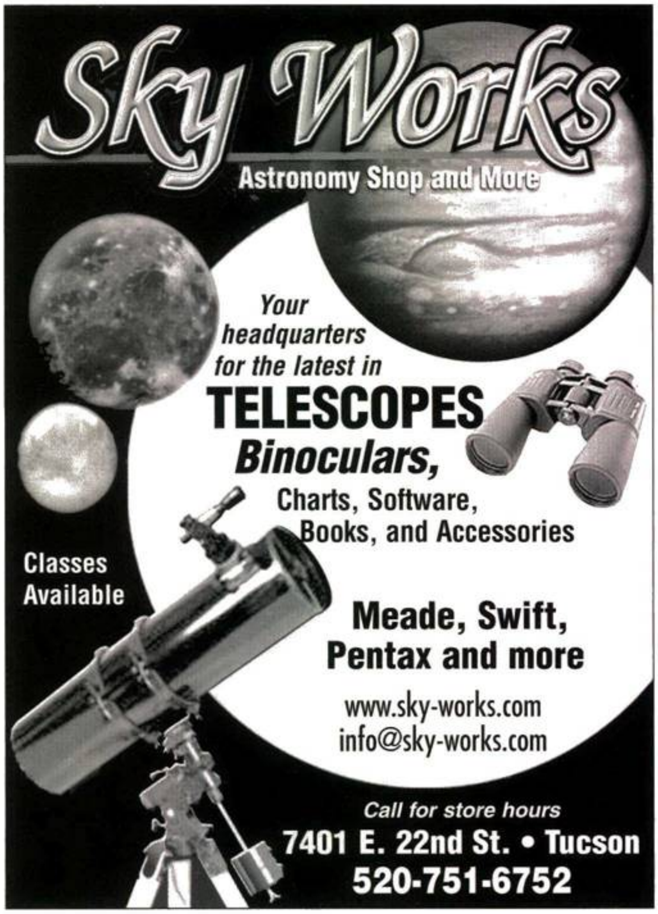

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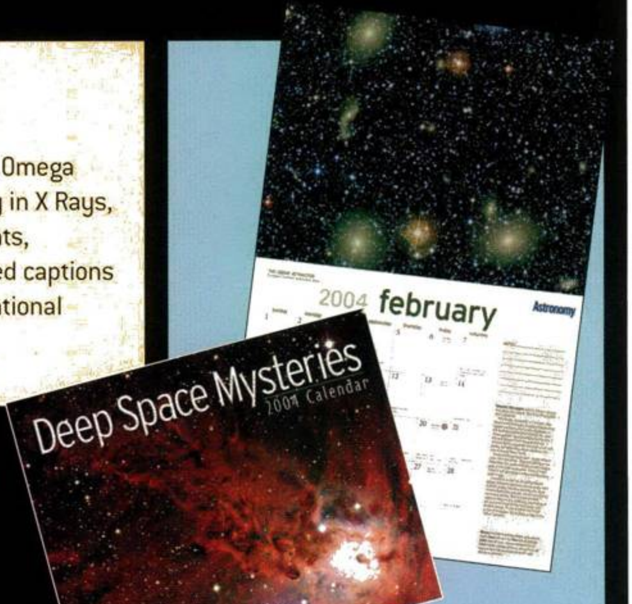

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Beginner's guide to astronomy

ASTRONOMY SPECIAL ISSUE NO. 1 • 2003

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MICHAEL STECKER

TONY AND DAPHNE HALLAS

TONY AND DAPHNE HALLAS

ROB GENDLER

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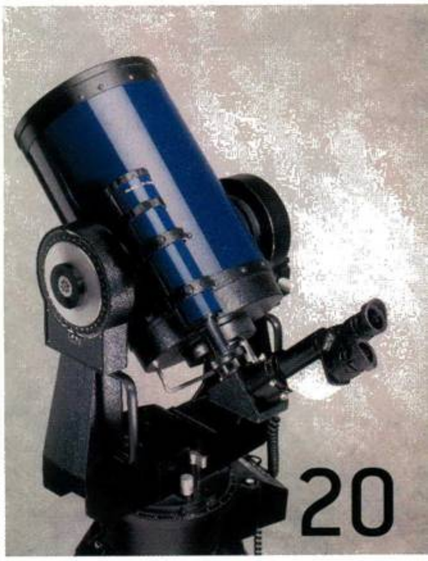
The new millennium offers amateur astronomers more opportunities for viewing, photographing, and understanding than ever before. Where will things go from here?



ASTRONOMY/WILLIAM ZUBACK

ON THE COVER Saturn is the most celebrated astronomical target for observers. Ask amateur astronomers what compelled them to become hobbyist astronomers, and they'll likely tell you a view of the Ringed Planet was involved. NASA

welcome to astronomy

Astronomy is the grandest subject in the world. In no other science can amateurs participate so easily, by simply walking outdoors on a clear night and looking skyward. No other science offers this type of hands-on opportunity, and astronomy offers the same laboratory to amateurs as it does to the most accomplished professionals. As editor of *Astronomy* magazine, I have the privilege of talking and working with hundreds of amateur astronomers throughout the course of a year. No matter what the person's background, social status, age, or career, I see the same thread running through each of them. This love for a knowledge of our universe is a powerful force. Once captured by it, you will never see yourself, Earth, the solar system, or the galaxy around you in quite the same way. An awareness of where we are in the grand scheme of things is a humbling, almost magical trait.

Being an amateur astronomer is being a naturalist — not with rocks or trees during the day but with starlight at night. You may simply enjoy scanning the gleaming winter Milky Way with binoculars. You might also enjoy watching meteors as they streak overhead. You may find that razor-sharp images of the planets, such as Mars and Saturn, are some of the most stunning sights you've seen. You may also find that exploring the battered surface of the Moon is like hovering over it in a spacecraft. Beyond the solar system lies the realm of stars, star clusters, and nebulae. Beyond our Milky Way Galaxy lies the realm of galaxies such as spirals, ellipticals, and lenticulars. These disks and spheres each hold billions of stars.

Astronomy offers an enlightening world that anyone can enjoy. Armed with binoculars or a simple telescope and a star atlas, the universe is yours to explore. Who wouldn't want to take up arms and do some exploring on the next clear night?

David J. Eicher
Editor

TONY AND DAPHNE HALLAS

Beginner's guide to
astronomy

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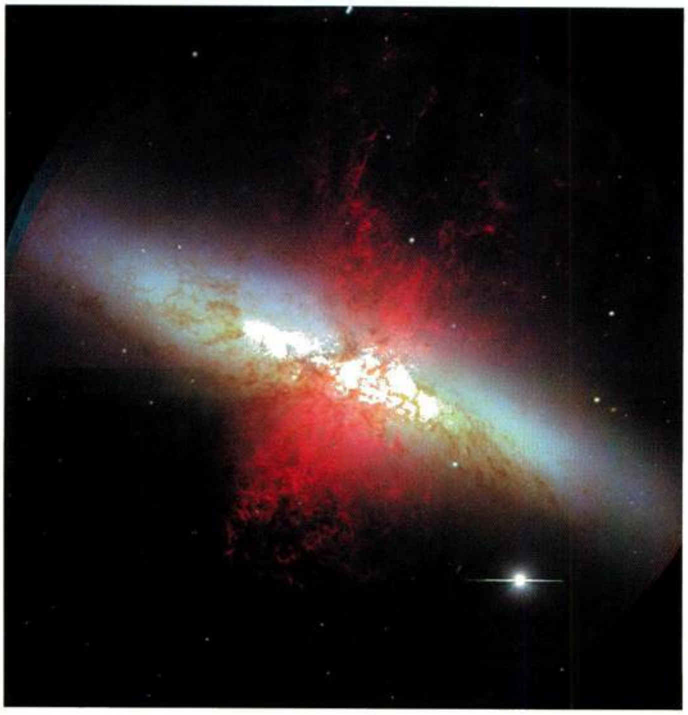
cosmic dust: an introduction to backyard astronomy



IRREGULAR GALAXY M82 was ▼ imaged with the Subaru Telescope in February 2000. Located some 12 million light-years from Earth, M82 has a disordered shape and dark lanes due to waves of star formation throughout its history. SUBARU TELESCOPE, NAOJ

Astronomy is like no other science. It can be enjoyed by anyone, at any time, who has the good fortune to have a clear sky overhead. Unlike archaeology, for example, astronomy's great laboratory is readily available to everyone, professionals and amateurs alike. And contrary to popular notion, either binoculars or a small telescope is quite capable of showing craters on the Moon, the moons of Jupiter, and many thousands of stars and galaxies. Hence, for a relatively small outlay of effort, and little or no money, it's possible to reach out beyond the fragile blue Earth and witness for yourself the universe that surrounds us.

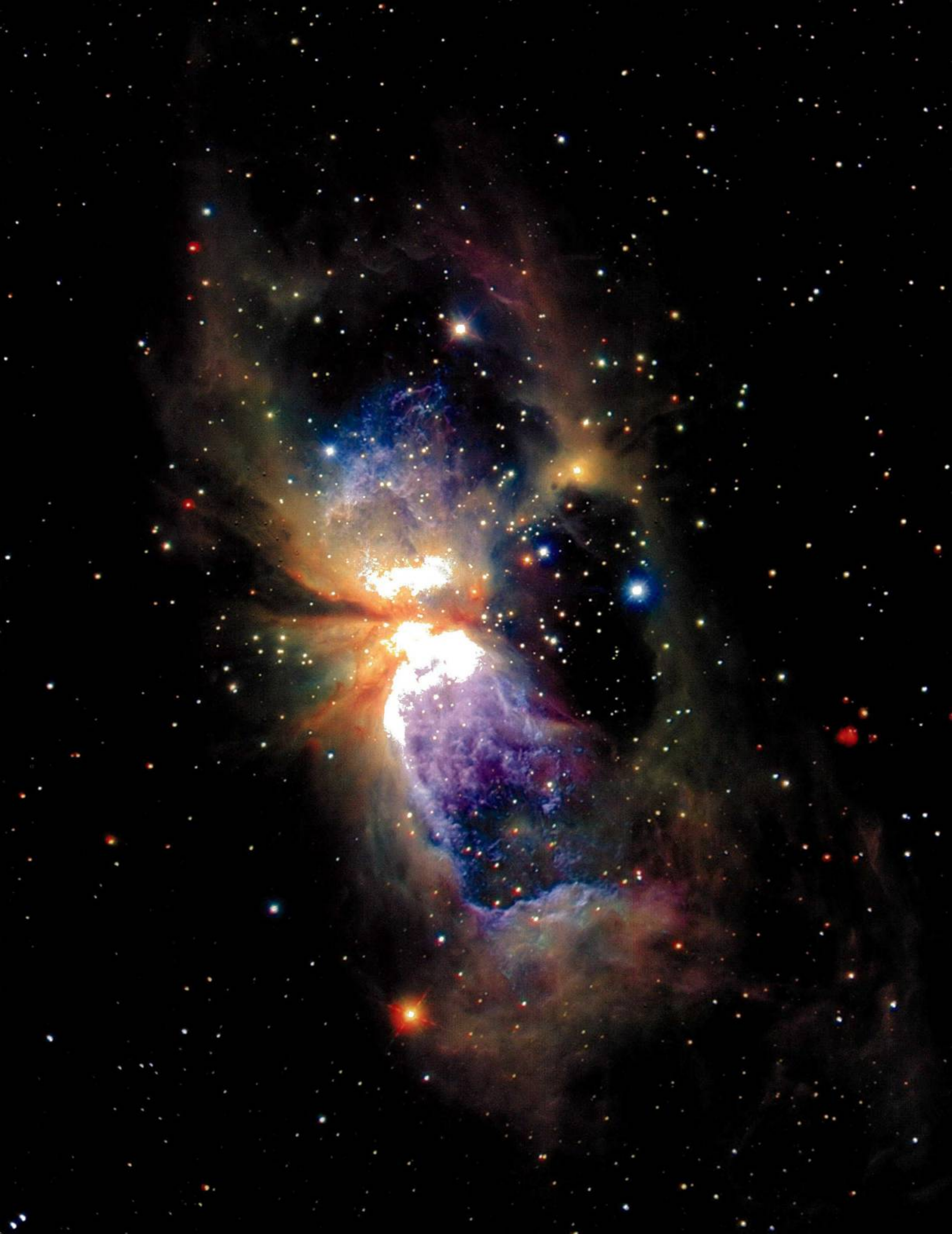
As a hobby, astronomy offers a wonderful journey of the imagination. We normally don't think of Earth as being constantly bombarded by light from objects scattered across the universe, but it is. All we need to do as astronomy enthusiasts is intercept some of that light, in the backyard at night with a telescope, to extend our vision from Earth's surface throughout our solar system, our galaxy, and to galaxies and quasars beyond. Astronomy is not limited to the nighttime, either. Daytime astronomy, a.k.a. solar observing, affords an opportunity to view up close the star that powers Earth and the solar system and makes life as we know it possible.

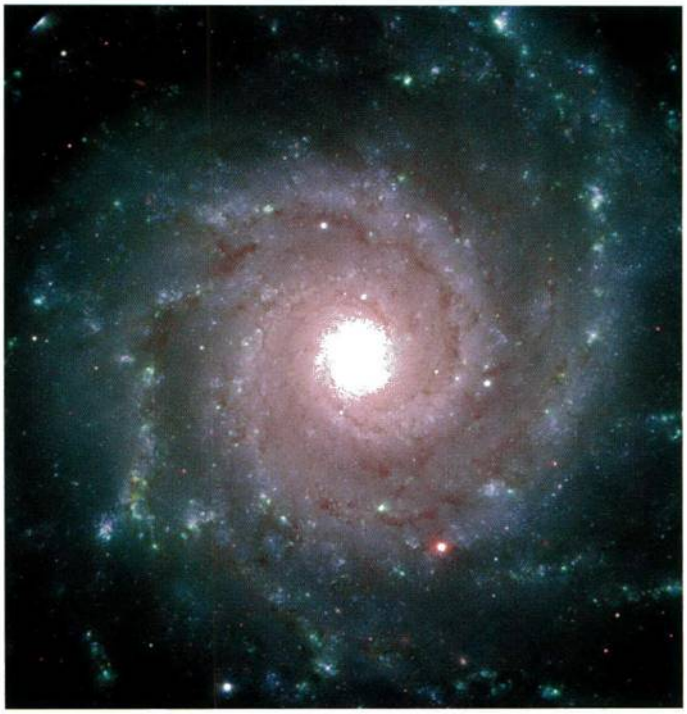
Before wading into this fascinating hobby, it's a good idea to review the basic structure of the universe. Our solar system consists of the Sun, our local star, around which the planets orbit. The nine planets in our solar system, in order of closeness to the Sun, are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto. In addition to the planets, the solar system contains small rocky and icy debris that we see as comets, asteroids, and meteors. Distances in the solar system are measured using astronomical units (AUs). One AU is the distance between Earth and the Sun, approximately 93 million miles. Our star is but one in our galaxy, the Milky Way, which contains several hundred billion stars. We exist in a spiral arm of the galaxy about three quarters of the way out from the galactic center, in a relatively sleepy area, and slowly orbit the center of the galaxy. Overall, the Milky Way's disk measures some 100,000 light-years across, a light-year being the distance light travels in one year (about 6 trillion miles). Yet even this gigantic scale is dwarfed by the immensity of the universe at large. Our galaxy is but one of 100 billion or more that exist in groups and clusters spread across the expanding shell of the universe. The farthest galaxies we can observe from Earth are 10 billion or more light-years away.

how to get started

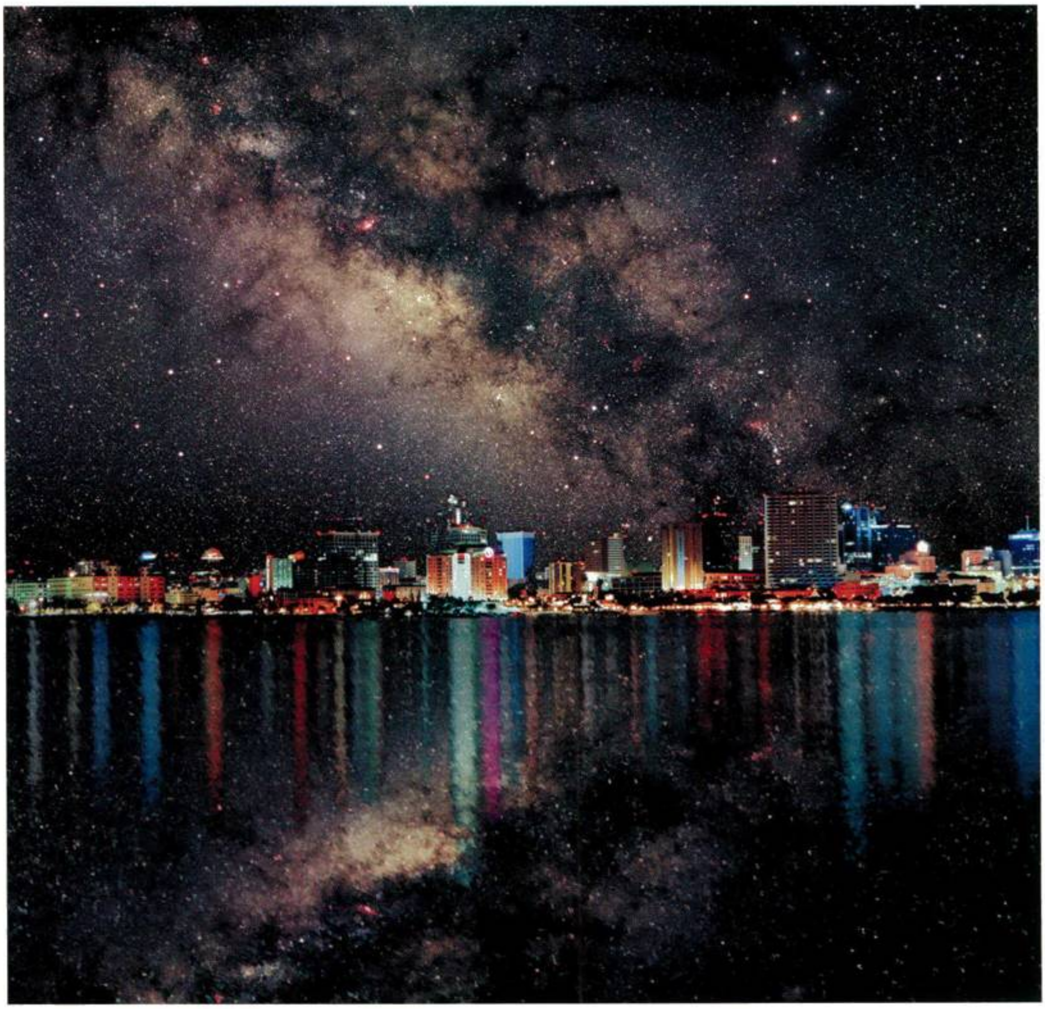
Astronomy offers everyone a broad spectrum of observational sights and activities. Millions of years ago hominids first gazed up in awe at the night sky. The twinkling points of light scattered across the heavens startled, confused, and perplexed ancient peoples like no other aspect of the natural world. Distant and mysterious, the stars seemed to symbolize

STAR-FORMING REGION S106, ► captured with the Subaru Telescope, shows a myriad of colors in this sharp infrared image. S106's hourglass appearance results from the outward flow of material from the central star — an object 100,000 years old and with a mass about 20 times that of the Sun. SUBARU TELESCOPE, NAOJ





M74'S BEAUTIFUL GALACTIC SWIRL shows the graceful symmetry of many spiral galaxies. This 8.1-meter Gemini North Telescope image was made from Mauna Kea, Hawaii. GEMINI OBSERVATORY/GMOS TEAM



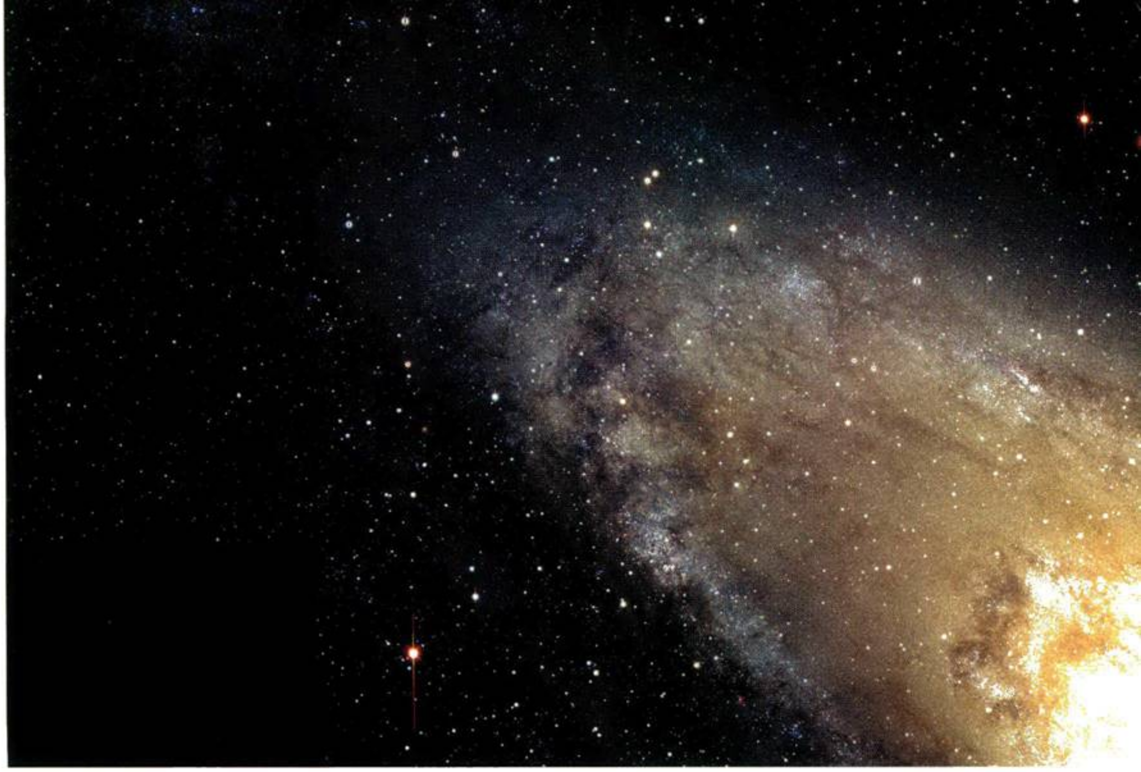
A BREATHTAKING COMPOSITE reveals the depth of the Sagittarius Milky Way set against a foreground of the city skyline of San Diego, California. Though fanciful, this scene reminds us that faint stars are visible only away from city lights. TONY AND DAPHNE HALLAS

something great and unknowable, attractive yet unreachable. Most of the stars seemed immobile; others moved relative to these "fixed" stars, as if directed by the gods. Time marched unrelentingly onward, and ages passed before Earth's intelligent mammals began to understand the nature of the stars.

Yet, in essence the stars, some of which we now know as planets, are sending us a message: that although we think of ourselves as somehow detached from them, they have played a significant role in making us what we are. Living beings are quite literally products of the stars — collections of cosmic dust organized in an incredibly complex way. Elements important to our chemistry were originally manufactured deep inside massive stars, which eventually exploded as supernovae, seeding the galaxy with the stuff of life.

Having been given such a fantastic entrance into the world and the surrounding universe, it's a sad testimonial that so few people are aware of their cosmic heritage. A great scientist once said that very nearly 100 percent of humanity is born, lives, and dies on the little blue planet Earth without ever being aware of the immensity of the universe or their relationship to it. But how can this change?

Wouldn't it be great if a relaxing, enriching hobby allowed you to peer out into the cosmos and better understand your place in it? Through amateur astronomy you may discover that you enjoy casually scanning the skies with binoculars or laying back and watching meteors flash overhead. You may find that viewing the Moon and its thousands of rilles, craters, and valleys is absolutely spellbinding. You may attach yourself to the planets, closely observing the rings of Saturn, the ever-moving moons of Jupiter, or the remote and challenging Pluto. You may become a deep-sky observer, finding fascination in hunting wispy nebulae or galaxies that lie millions of light-years away. You may be a work-shop astronomer who grinds mirrors and builds finely crafted telescopes. You may fall in love with imaging by camera, CCD, or video and collect your personal set of astro images. Or you may want to casually read about astronomy and what scientists are finding out about the universe without ever venturing outside to observe.



THE ANDROMEDA GALAXY (M31), a relatively nearby neighbor, contains two hundred billion stars locked in its gravitational grip. Several billion years from now the Milky Way and M31 will merge as the two slowly move together in space. NOAO/AURA/NSF

naked-eye astronomy

Whatever path you choose, astronomy is a large and active hobby that has room for every kind of enthusiast, demands little, and offers a lifetime of fascination. The best way to begin your enjoyment of the night sky is to obtain a simple star chart (the center spread map in *Astronomy* magazine is ideal), head outdoors on a clear, moonless night, and learn a few constellations (which are arbitrary patterns of stars created by ancient cultures to, in many cases, honor mythical figures). This requires nothing more than some warm clothes (or in the summer, insect repellant), a mug of coffee or tea, and a little patience. Your first instrument will be your eyes alone, which under a country sky will reveal thousands of stars, some as faint as 6th magnitude. (The magnitude system provides astronomers with a measure of visual brightness, with larger numbers representing fainter objects. The planet Jupiter, for example, normally shines at around –2 magnitude, Saturn at magnitude 0, and the brightest stars in the Little Dipper at magnitude 3 (except for Polaris, the North star, which shines at 2nd magnitude. The faintest stars visible to the naked eye are about 6th magnitude, the faintest stars visible in most backyard telescopes about 12th magnitude.) Pick out some commanding star groups to focus on. In the summer, Sagittarius, Scorpius, and Cygnus are favorites. In autumn check out the Great Square of Pegasus. During winter you can view Orion and Taurus. As spring thaws the landscape, constellations like Ursa Major, Boötes, and Virgo will greet stargazers in the evening sky.

As you learn the bright constellations, you can branch out into identifying some fainter ones. These include Draco (summer), Pisces (autumn), Eridanus (winter), and Cancer (spring). As your knowledge of the sky grows, your ability to find interesting objects — stars, star clusters, and galaxies — will allow you to show friends some of our distant neighbors in the universe should you one day get a telescope.

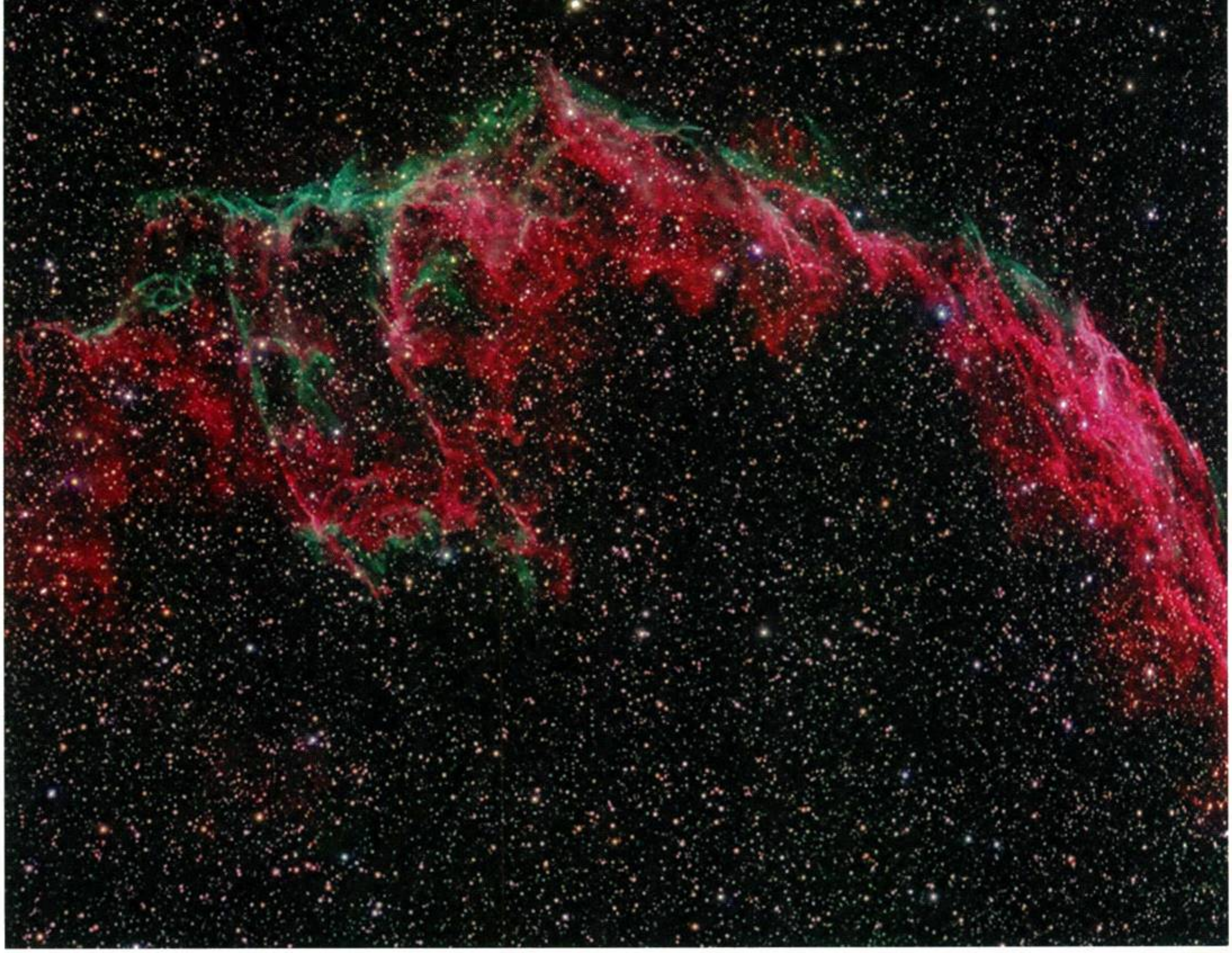
Don't neglect the planets, either, which, as they orbit the Sun, move in the sky relative to the stars. Brilliant Venus — the "morning star" or "evening star" — is dazzling and unmistakable, although it never strays terrifically far from the Sun. Fainter Mercury is visible to the naked eye as well but remains even closer to the Sun than Venus. Bright planets that traverse the path of the ecliptic — the plane of our orbit as we see it projected on the sky — include Mars, Jupiter, and Saturn. Their motion is slow enough that you can effortlessly follow their changes against the background stars over days, weeks, and months. Uranus is barely visible to the unaided eye under a dark sky, so picking it out among the stars is an invigorating naked-eye challenge. The two most distant planets, Neptune and Pluto, are beyond the reach of human eyes alone. To enter the magnified world of the cosmos, you'll need good binoculars. A standard, off-the-shelf model labeled "7x50" will do nicely.

astronomy with binoculars

By providing a jump in magnification and the added light-gathering power of a lens, binoculars bring you much closer to a wide array of astronomical objects. One of the most magical eras of my astronomical observing was that period of nearly a year when I roamed the sky armed with only binoculars and the expectation of what I might find. Without the experience and the telescope that came later, I had little idea of what various objects might look like. Yet nearly every clear night I carried outside a simple star chart and my trusty binoculars and scanned the stellar veil of the Milky Way, the barren fields of the spring and autumn skies, and the frosty, bright constellations of winter. Every star and every fuzzy object brought a new fascination and a new mystery to explore.

a backyard observatory

At some inevitable point, you're going to want to make the jump



THE VEIL NEBULA consists of the eerily glowing gas thrown off by a star that exploded tens of thousands of years ago. Located in the constellation Cygnus, it is visible to owners of medium-sized telescopes. TONY AND DAPHNE HALLAS

to a telescope. This marvelously simple instrument consists of mirrors and/or lenses set in a tube. Owning your own telescope allows you to get close to the universe, in effect, by allowing you to have your own backyard observatory. Three basic types of telescopes exist. The simplest is a Newtonian reflector, a telescope that employs a primary mirror to focus an image with the help of an eyepiece. Simple reflectors offer exceptional value by providing the biggest possible optics — and therefore the most light gathering power — per dollar. A good 6-inch reflector will show the phases of Venus, details on Mars, Jupiter, and Saturn, as well as hundreds of deep-sky objects. Keep in mind, the larger the mirror, the better and brighter the view. The limiting factors include expense and portability. At some point a telescope stops being a device that you can easily carry around.

The second major telescope type is a refractor, a lens-based instrument that dates to the design used by Galileo back in 1610. Quality refractors provide razor-sharp images and good contrast and therefore are particularly well-suited for observing planets and other objects where seeing detail is critical. However, refractors are relatively expensive inch for inch, and large refractors are just that — physically very large.

Catadioptric telescopes constitute the third major type and consist of lens/mirror combinations. They are extremely portable because they employ optics in a folded light path so their tubes can be kept short. They are moderately expensive, but offer superb qualities for backyard observers.

exploring the solar system

Okay, you've got a telescope. Now what are you going to look at? The obvious first choice is to scope out the solar system, our bright and easily observed group of celestial neighbors. The brightest of them all is of course the Sun, the star that powers our bustling activities on Earth. Solar observing means setting up your telescope during the day when it's easy to see how to operate it. However, viewing the Sun with any kind of optical aid is potentially very dangerous. Never observe the Sun without a properly chosen and attached solar filter on the front end of your telescope. Never use a solar filter that attaches to an eyepiece! Quality solar filters remove powerful radiation from the focused sunlight that could blind you in a split second. With a proper solar observing setup, however, you can observe sunspots and other phenomena safely and at your leisure.

The most popular object for beginning astronomers is the Moon. Speckled with mare (literally, "seas" as they resemble vast oceans) and pocked by craters, the lunar surface offers many hours of exploration with even the smallest of telescopes. The range of detail is so great and the Moon so different in appearance during its cycle of phases that you may find yourself hooked on lunar observing for a lifetime. Do note, however, that the best time to observe the Moon is not when it is full. This is because all shadow detail on the Moon is at a minimum at this phase. Rather, do most of your lunar observing two or three days on each side of First Quarter. Pay particular attention to the area of the terminator — the line dividing the light and dark sections. This is the line of sunrise, where shadows extend the longest.

At least once in a while, however, you'll want to explore the planets. The "big three" from a telescopic perspective are Mars, Jupiter, and Saturn. Particularly when it is relatively close to Earth, Mars's orange-colored disk shows a surprising amount of albedo features — that is, dark regions visible against the planet's brighter surface. Jupiter's mighty bands and belts show easily in small scopes, as do its ever-present Galilean moons, which comprise a

THE LAGOON AND TRIFID NEBULAE comprise one of the richest star-forming regions in the galaxy. Here gas, recycled from dying stars, is coalescing back into hot, new, infant suns. JASON WARE ▲

THE NORTH AMERICA NEBULA (NGC 7000) in Cygnus reminds us that everywhere we look in the sky, we seem to see something familiar. JASON WARE ◄

WHAT OF PLANET EARTH? Our ► humble home is one of more than 100 planets currently known in the Milky Way, and this number is growing month by month with new discoveries. With hundreds of trillions of stars in the universe, how many of the accompanying planets may house life? NASA

FAINT, CHALLENGING GALAXIES ▼ like NGC 300 in Sculptor can be spotted in moderate-size telescopes; such objects are tens of millions of light-years away.

MARTIN C. GERMANO

BRILLIANT SHADES OF AURORAE can be visible on nearly any clear night as seen from mid- to far-northern or southern latitudes. These aurorae are caused by cascades of energetic particles cast off the Sun, which spiral down above Earth's poles. JAY BRAUSCH

miniature solar system revolving about the mighty planet. At times, even the Great Red Spot is visible.

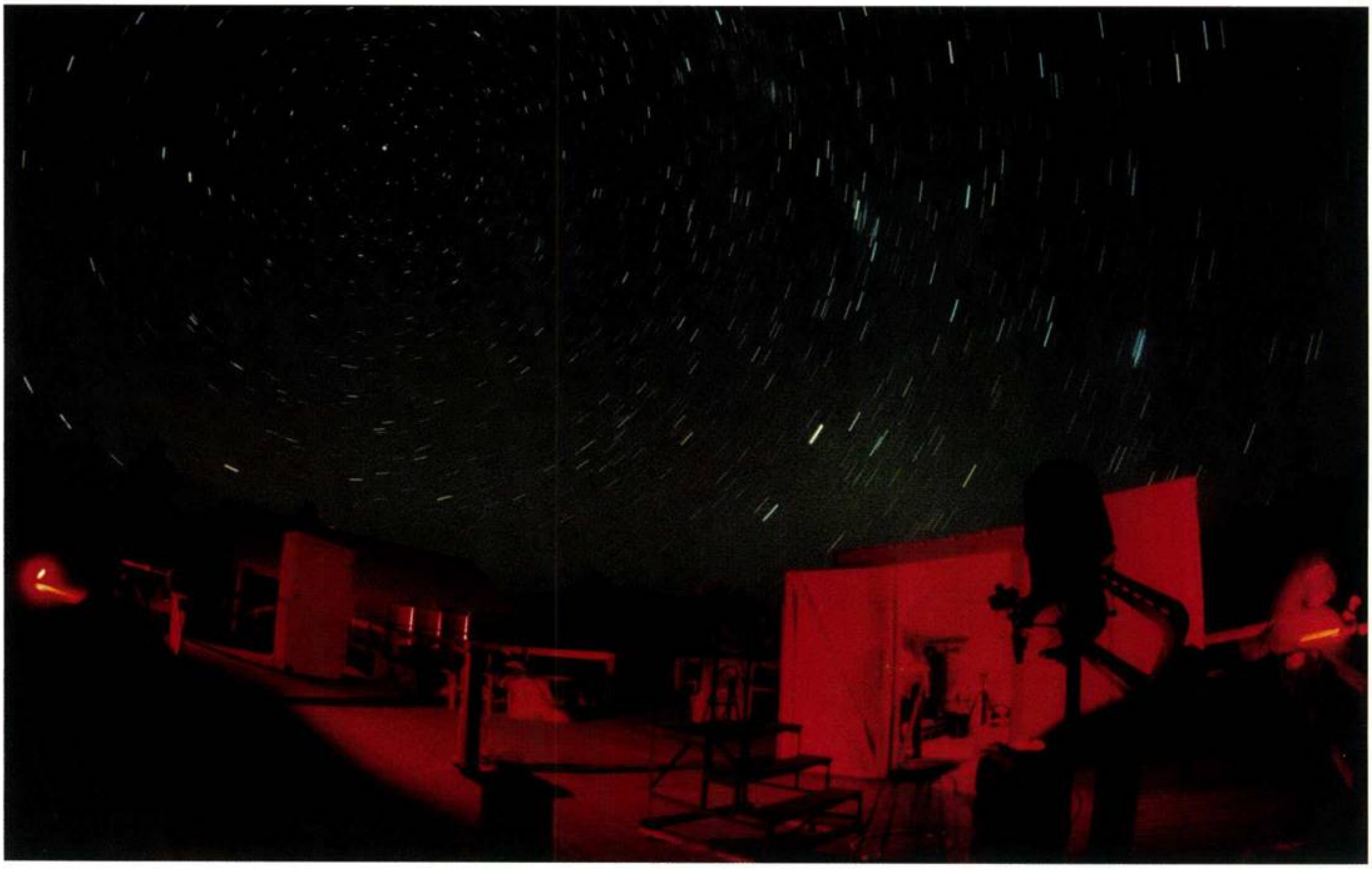
Saturn is the greatest spectacle of the solar system. I'll never forget the night in 1975 when I first glimpsed Saturn's rings through a small reflecting telescope. The planet hovered like a magic illusion, and I was simply awestruck that the sight was so easily visible from a friend's backyard.

Other planets are visible, too. Venus and Mercury show a cycle of phases similar to the Moon's. Because they lie closer to the Sun than Earth, Uranus and Neptune are challenging, distant worlds, visible in telescopes as nonstellar disks with blue-green hues. Pluto, the last planet of the solar system, is so small and so remote it requires an 8-inch telescope to be seen and even then it appears only as an extremely faint "star."

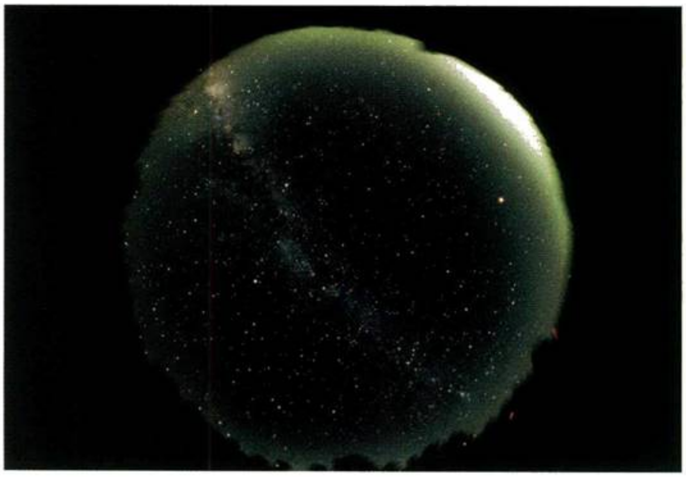
When observing planets, you'll notice that compared with many sky objects they are very small. Astronomers measure the sizes of objects in the sky using degrees, arcminutes, and arcseconds. One degree (abbreviation: °) contains sixty arcminutes (abbreviation: '), and one arcminute contains sixty arcseconds (abbreviation: "). The Full Moon, for example, is about one-half degree, or 30', across. Many galaxies and nebulae span 10' or so. Planets, however, are much smaller: the disk of Mars is typically less than 10" in diameter.

to the depths of the universe

Sun, Moon, and planets do not a universe make, however. The sky is also filled with billions of stars belonging to our galaxy, the Milky Way, and many peculiar inhabitants known as deep-sky objects. Many of these interesting telescopic objects are double, multiple, or variable stars — star systems consisting of more than one sun or systems that vary in light output for a handful of reasons. Other deep-sky objects are more exotic residents of the Milky Way. Star clusters are groups of hundreds or thousands of suns born together from a common cloud composed of dust and gas. These collections of stars slowly revolve about the center of the galaxy until they break apart and travel separate stellar paths. Nebulae are gas and/or dust clouds of several distinct types. Bright nebulae represent the extremes of stellar life, generally being gas clouds associated with star birth or death. Dark nebulae are scattered clouds of dust floating throughout the galaxy whose presence is known only when they block light from bright objects that lie beyond.



NORTHERN STARS TRAIL around ▲ Polaris, the "Pole star," in this time exposure taken in 1991. The well-equipped amateur observatory, seen in the foreground, is ready for a night of viewing and astroimaging. GARY A. BECKER



A CAMERA'S ALL-SKY VIEW ► reveals the glowing band of the summer Milky Way stretching across the sky from horizon to horizon. The greenish glow around the horizon is caused by light pollution from a nearby city. MARK A. COCO

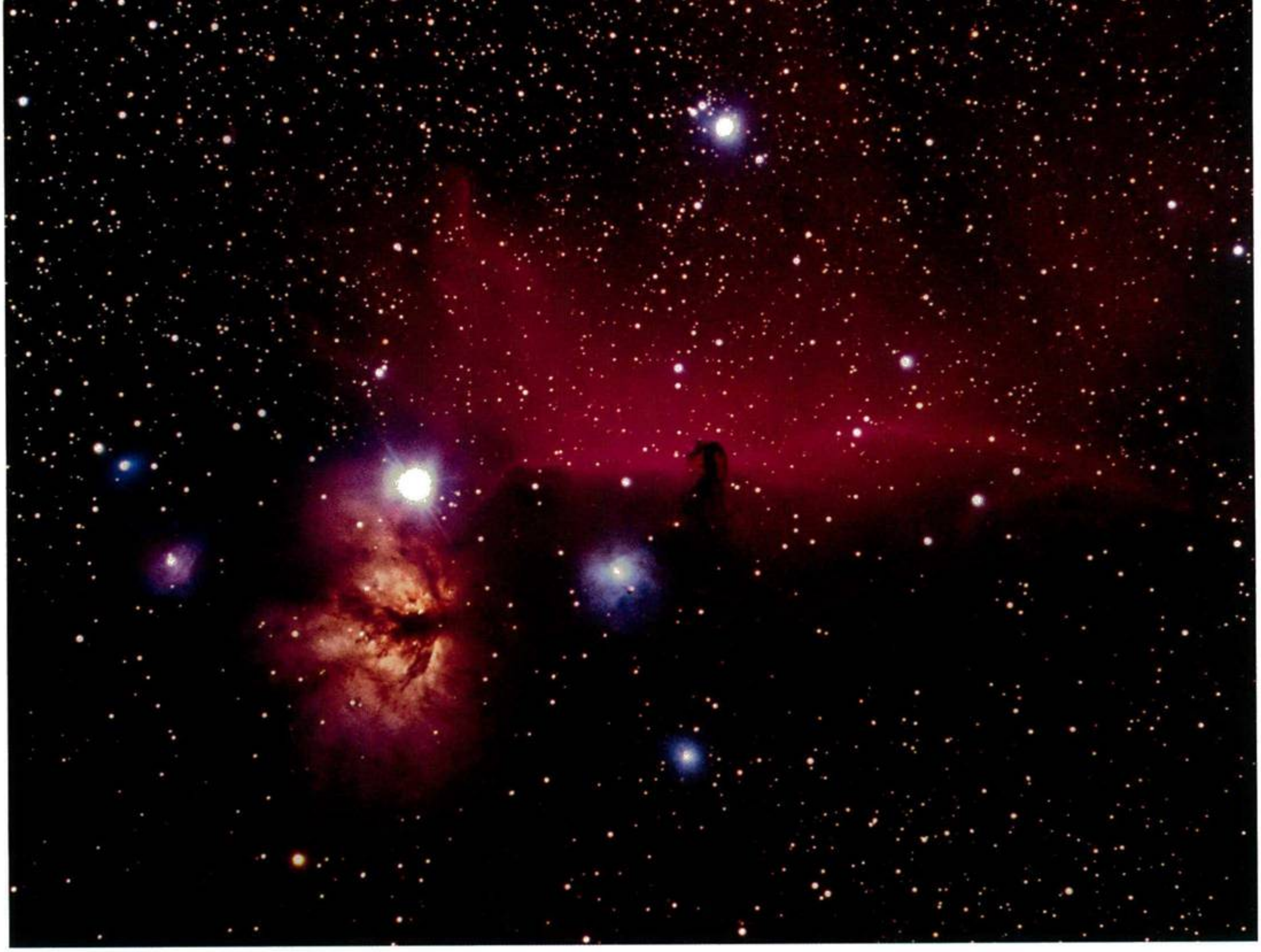
Numerically, however, another type of deep-sky object outdoes all others in the entire sky. Thus far everything we've surveyed has been a component of our solar system or our galaxy. Yet the universe is composed of countless billions of galaxies, arranged in groups, clusters, and superclusters. Thousands of galaxies are visible with a backyard telescope, as are a small number of their highly energetic cousins, quasars.

In observing deep-sky objects, one technique is particularly useful. Averted vision, looking slightly away from an object, uses the most sensitive part of your eyes — the rods. These receptors are best at detecting dim light, so this technique is quite good at letting you see more detail in faint objects.

astronomical photography

You're hardly limited to observing the universe. Many amateurs collect their own images of the sights they have seen in the solar system, Milky Way, and beyond. Astronomical photography is easier than it sounds, and is becoming easier every day as improved cameras and films hit the market. The simplest way to start is with camera and tripod, taking photos of star trails, meteors, and nightscapes. This is a simple procedure that entails setting up the camera, loading it with fast film, composing a shot that includes some horizon landscape detail as well as sky, and opening the shutter for several minutes. The results will surprise you.

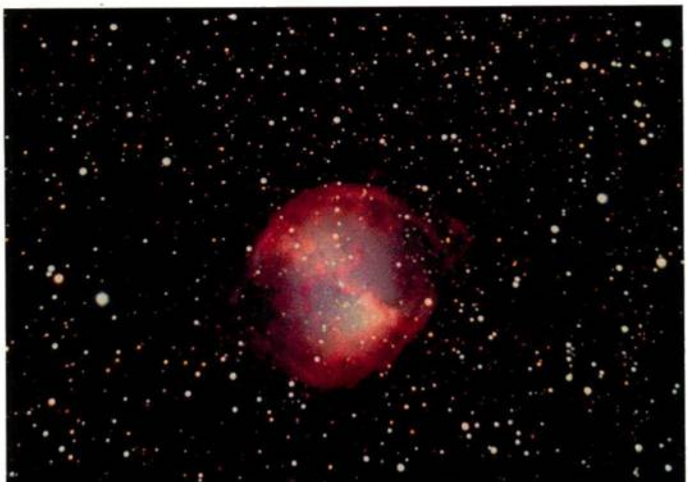
Of course, more sophisticated astrophotography is possible as well. Guiding the camera so it tracks the motion of the stars across the sky produces stars-as-dots rather than stars-as-streaks results. It's possible to take guided



portraits of constellations, of deep-sky objects, and of the Moon, Sun, and planets. Ultra-sophisticated electronics are also invading the world of astronomical imaging. CCD chips and computers have taken their places alongside cameras and darkrooms. High-end astroimaging is possible today, and in section three we will look at the possibilities it offers.

a walk through the universe

Before exploring all the options, enter the hobby of astronomy at a slow walk. If an astronomy club exists in your area, drop in for a meeting and get to know the flavor of the hobby. Make sure you subscribe to or have access to the leading magazine of the astronomical hobby, *Astronomy*. If possible, attend a few star parties to glimpse distant worlds through the eyepiece of a fellow amateur's telescope. Try out different types of equipment and see what you like best. Be sure you observe from the darkest possible site, away from the light pollution of city and suburban skies. Astronomy is a hobby that will expand as our consciousness of the universe expands. Approach your exploration of the universe with an open mind. Harvard astrophysicist Martin Harwit's classic 1981 quote, from his book *Cosmic Discovery*, still rings true: "Astronomers have identified to date only 10 to 20 percent of the phenomena that exist in the universe. What an exciting, unpredictable future lies ahead!"

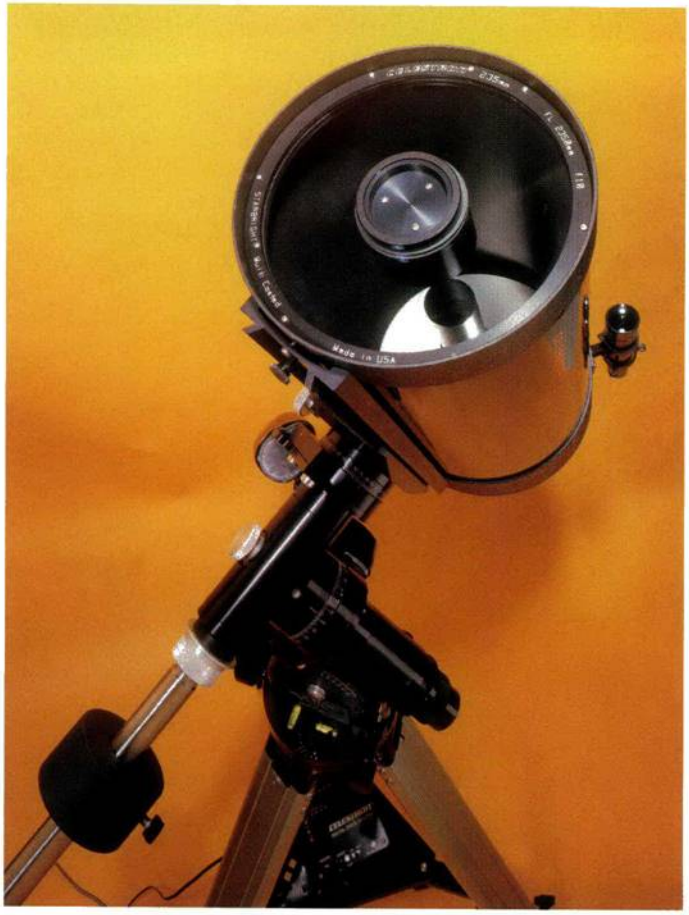


THE HORSEHEAD NEBULA in Orion, a magnificent example of a dark nebula, is an extreme challenge for visual observers but can be recorded relatively easily by astroimagers. ▲ GEORGE GREANEY

A COSMIC APPLE CORE, the Dumbbell Nebula in Vulpecula, can be spotted in a 2-inch telescope. An 8-incher shows its distinct shape and even the faint star at its center that created the gas cloud. ◄ GEORGE GREANEY

from naked eye to observatory: equipment for skygazing

A CELESTRON SCHMIDT-CASSEGRAIN telescope poised on a German equatorial mount would make a suitable instrument for photographing deep-sky objects or planets. ASTRONOMY/WILLIAM ZUBACK



One of the greatest facts about observing is that people already have the finest equipment in the business — human eyes. A stroll under the stars on a dark night will demonstrate the value of the eye. Its resolving power and dynamic range, which enable bright and faint objects to be seen, are amazing. It can show you the brightest astronomical object, the Sun, on a clear afternoon. (You should never look at the Sun without a proper filter, however.) It can show you all of the planets except Neptune and Pluto. It can show you meteors, comets, and aurorae. And it can show you thousands of stars down to about 6th magnitude. (The magnitude system, remember, is a measure of an object's brightness, assigning brighter objects smaller numbers.)

Although your eyes are your fundamental piece of equipment, they can show only so much. To see faint objects, to see astronomical objects up close, and to locate astronomical objects, you'll want to use a telescope or binoculars and a good star atlas. Choosing the telescope or binoculars that is right for you takes some degree of patient consideration. The star atlas is somewhat more straightforward, however.

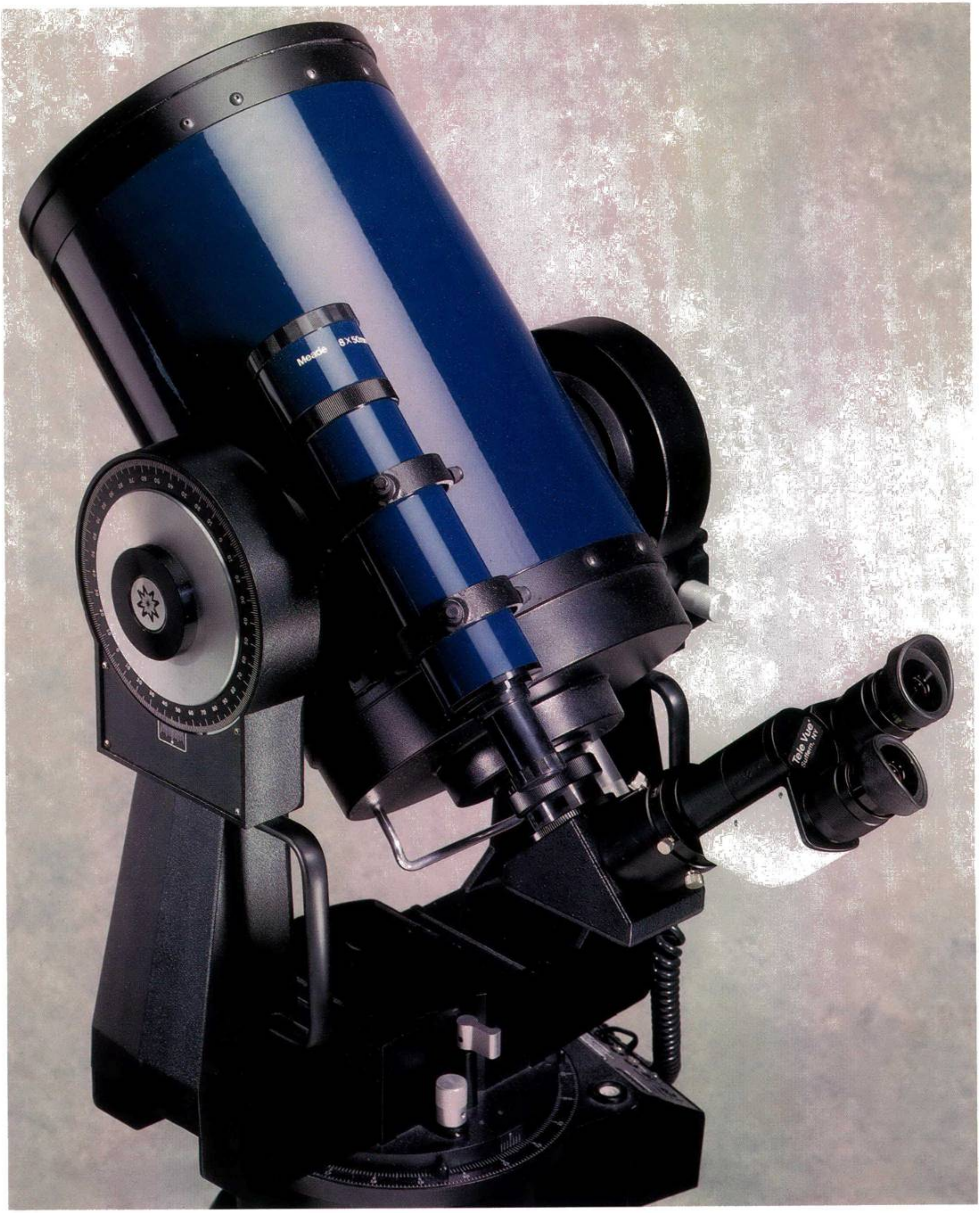
The first thing a star atlas should do is familiarize you with the constellations visible at the time you observe. To begin with, check the Star Dome map in the center of each issue of *Astronomy*. For a more detailed map that shows the positions of fainter stars and deep-sky objects, you may wish to use *The Observer's Sky Atlas* by Erich Karkoschka (Springer-Verlag, New York, 1990), *The Cambridge Star Atlas*, 3rd edition, by Wil Tirion (Cambridge University Press, 2001), or the magnificently detailed *Sky Atlas 2000.0*, 2nd edition, by Wil Tirion and Roger W. Sinnott (Cambridge University Press. New York, 1999).

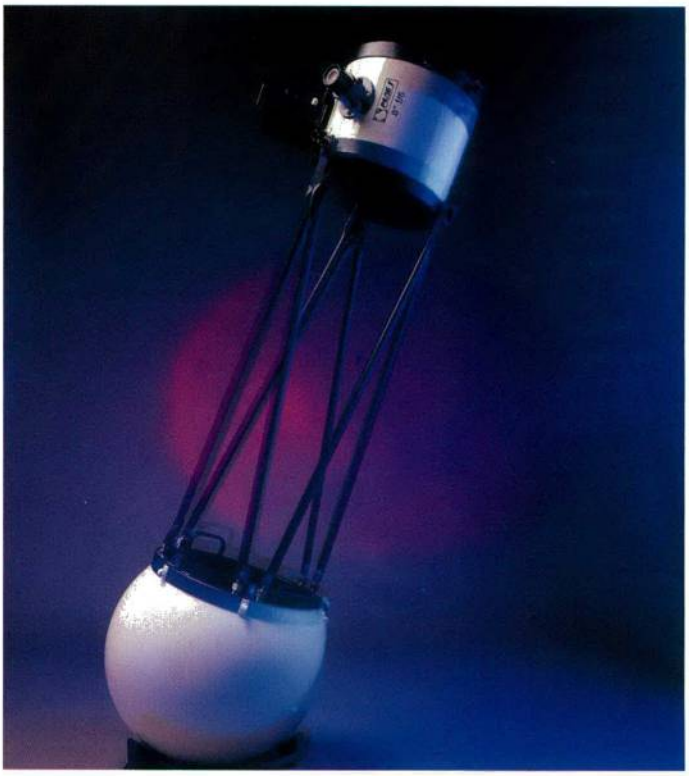
how to choose binoculars

If you want to begin looking at the sky with optics, the best way to start is with good binoculars. They'll let you explore the wonders of the sky with a wide field, scan the summer Milky Way, view the bright star clusters of winter, and discover the remote realms of the galaxies in spring and autumn. The experience you'll gain finding your way around the sky armed with just binoculars will be invaluable later with a telescope, and the time spent with binoculars will let you think about the attributes you'll look for in a telescope, a greater investment of both money and time.

Many beginning stargazers think that binoculars can't possibly have the power to be useful in astronomy. Not true. As you'll see, magnification is not the most crucial aspect of an optical instrument. In fact, the low-magnification, wide fields provided by binoculars are a great help in seeing many objects. I recommend beginning with 7x50 binoculars — lenses that measure 50 millimeters across and magnify seven

A MEADE SCHMIDT-CASSEGRAIN ► telescope fitted with a Tele Vue binocular eyepiece system. This arrangement would yield pseudo-3-D views of many objects, solar system and deep-sky. ASTRONOMY/WILLIAM ZUBACK


Meade
8×50mm
Tele Vue
Suffern, NY



A TELE VUE GENESIS REFRACTOR provides a very sharp view for high-resolution observing of planets, double stars, and small nebulae and galaxies. ▲

ASTRONOMY/WILLIAM ZUBACK

THIS ORION 4.7-INCH REFRACTOR packs a great deal of muscle into a compact package for visual observing and photography. ◥

ASTRONOMY/MAGGIE MCKEE

A PORTABALL, a commercially-produced Dobsonian scope, demonstrates the large aperture and open-tube structure of many Dobsonian instruments. ▶

ASTRONOMY/WILLIAM ZUBACK

times — because they're big enough to show you stars, bright star clusters, and bright galaxies, but small enough to hold comfortably without a tripod.

moving to a telescope

When you get the bug to buy a telescope, make sure you research the options first. No "best telescope" exists for all purposes, and the type of instrument you'll want to get will depend on your observational interests. Do you want to simply look at objects? Do you want to make long exposure, guided photographs of them? Are you predominantly interested in planets, double stars, and the Moon? Or do your tastes run toward star clusters, nebulae, and galaxies? Do you have a dark sky in your backyard, or will you need to transport your scope to a good observing site? Such considerations weigh heavily toward the type of telescope you'll want.

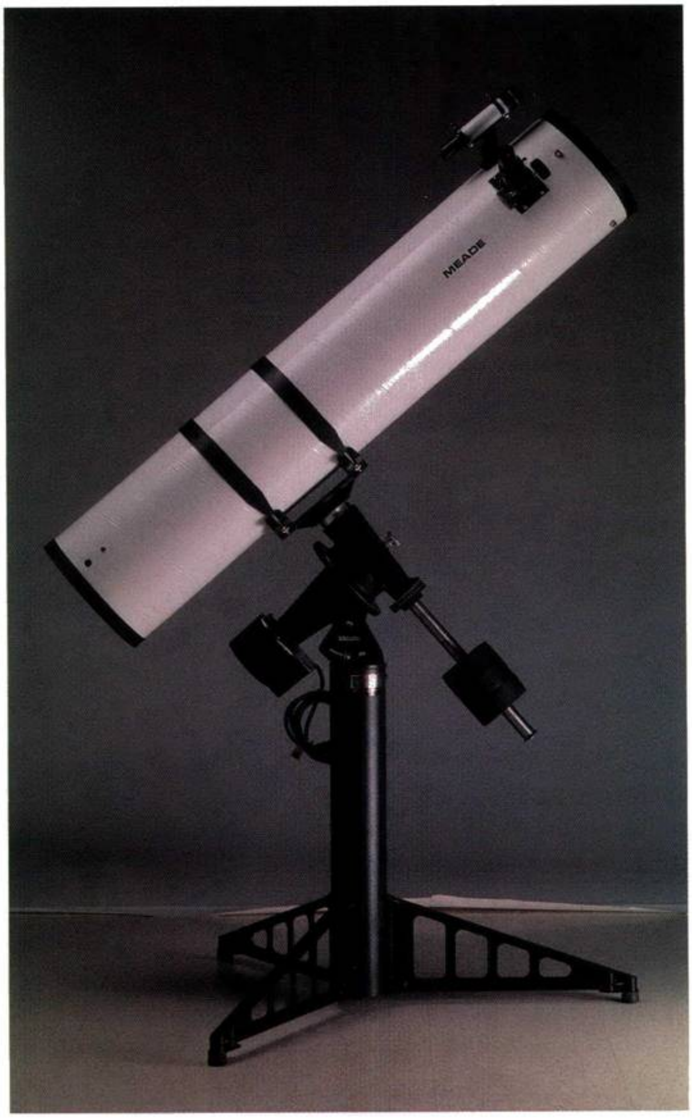
Three basic classes of telescopes are commercially available, each sold by several manufacturers. Their advertisements can be seen regularly in the pages of *Astronomy*. The "classic" type of telescope is a refractor, with its iconic long, white tube and elegant tripod. This is the design used by Galileo in the 17th century. Refractors use lenses at the front (skyward) end of the telescope to focus light into an eyepiece that sits at the rear end of the tube. *Refractor* simply derives from refracting, or bending, incoming light rays to a common focus. Achromatic (two-lens) designs have been available for years and are relatively good buys, but they produce minor aberrations — color distortions — in the images they deliver.

Wil Tirion
CAMBRIDGE STAR ATLAS 2000.0
Sky Atlas 2000.0
NORTON's 2000.0
URANOMETRIA 2000.0
OBSERVER'S HANDBOOK 1994
ATLAS OF THE MOON
Stars and Planets

April Night Sky

Apochromatic (three lens) refractors are superb optically, providing true-color images of planets and pinpoint stars. Refractors typically have long focal lengths, meaning they provide relatively small fields of view. Thus they are extremely good instruments for observing the Moon and planets and small objects like double stars and planetary nebulae. Recently, manufacturers have produced shorter focal length apochromats that provide wider fields of view. These telescopes are optically superb, but the quality comes with a very high price tag.

Reflectors are the second major class of optical design. Modeled after the design used by Isaac Newton, reflectors use a mirror in the rear of the telescope and a small secondary mirror suspended near the front of the tube. Incoming starlight is reflected off the primary (rear) mirror, to the angled secondary, and into an eyepiece positioned on the side of the tube near the front end. These instruments typically have shorter focal lengths than refractors and hence provide wider fields of view, making them good telescopes for deep-sky observing. Their tubes are typically much shorter than those of refractors, making them much more portable per inch of telescopic aperture.



AT THE READY. Keeping star charts and accessories handy will enable you to assemble a log of what you've seen in the sky — a great keepsake to read through on cloudy nights. ▲

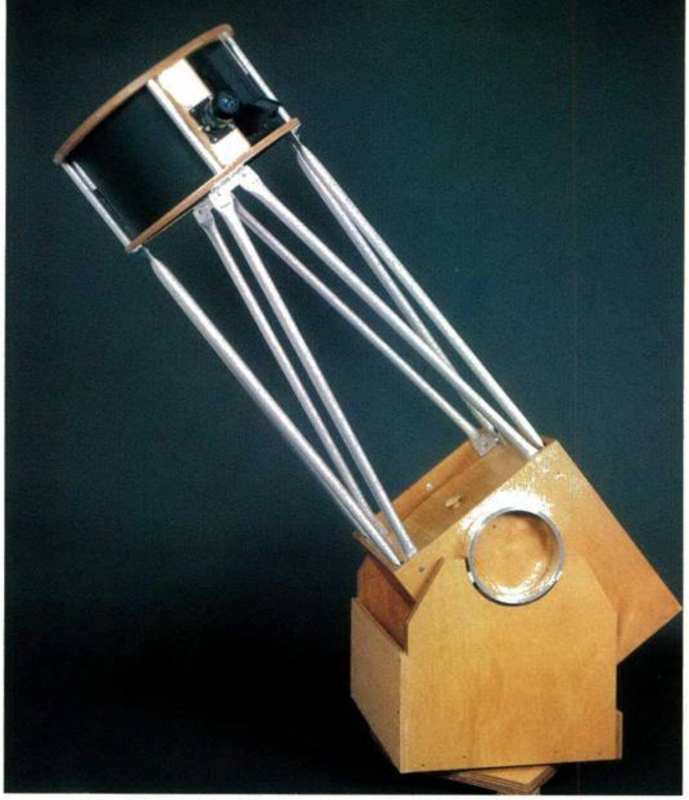
ASTRONOMY/WILLIAM ZUBACK

STAR ATLASES, MAPS, AND OBSERVING HANDBOOKS are available in droves on the market. ▼

ASTRONOMY/WILLIAM ZUBACK

THE CLASSIC NEWTONIAN REFLECTOR, with its white tube, eyepiece top, and German equatorial mount, is still hard to beat as an all-purpose telescope. ◄

ASTRONOMY/WILLIAM ZUBACK



Philips'
Planisphere
shows the principal stars visible for every hour in the year
for Latitude 42°N
USA • Southern Europe
• Northern Japan
Western Horizon
Eastern Horizon
SEPTEMBER
AUGUST
JULY
JUNE
MAY
APRIL

A LARGE, HOME-BUILT DOBSONIAN telescope packs as much aperture as the builder can handle, maximizing the view of faint objects such as distant galaxies. ▲

ASTRONOMY/WILLIAM ZUBACK

A HANDY PLANISPHERE, or star wheel, will let you dial up the correct night and get a view of which stars are visible at any particular time. ◄

ASTRONOMY/WILLIAM ZUBACK

NOTHING BEATS 7x50 BINOCULARS to get started with astronomical observing. ►

ASTRONOMY/WILLIAM ZUBACK

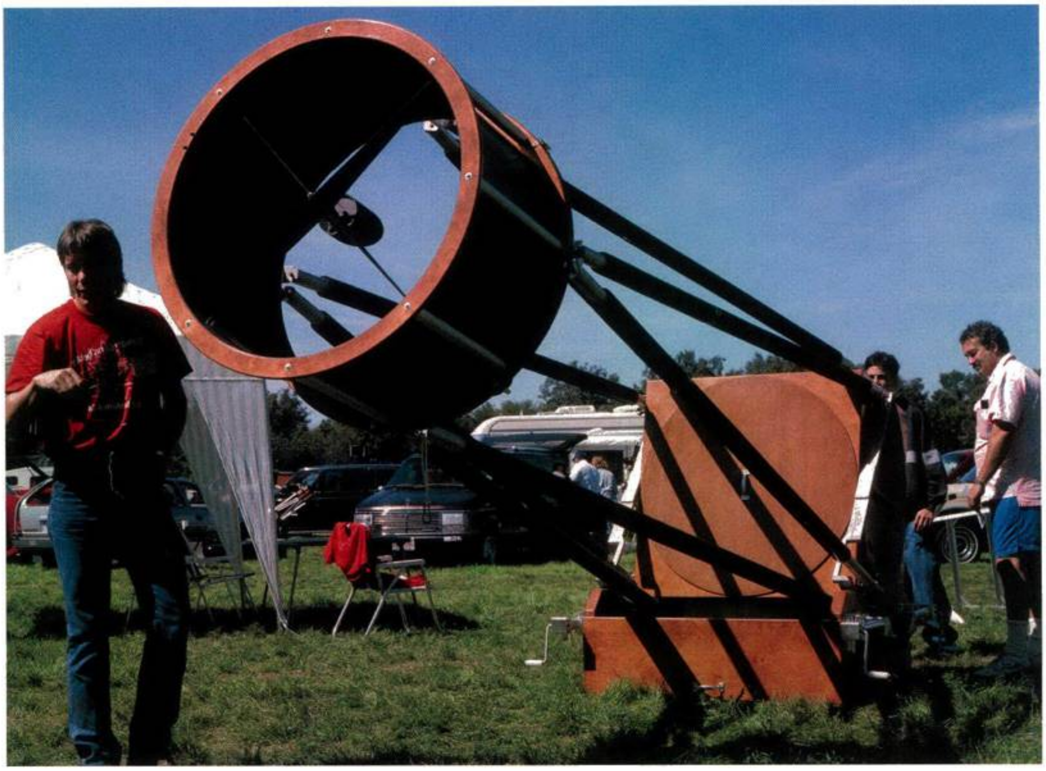
The third major class of telescopes is the catadioptric instrument, a combination of lenses and mirrors. The most popular type of catadioptric scope is the Schmidt-Cassegrain (SCT), which uses primary and secondary mirrors like a reflector but also employs a thin corrector plate at the front end. The design bounces the image back through a hole in the primary mirror to an eyepiece at the telescope's rear. Because of the folded light path, SCTs pack relatively long focal lengths into a compact package, making them highly portable. A similar type of catadioptric is the Maksutov-Cassegrain telescope. All types of catadioptric telescopes are ideal for the Moon and planets and because of a vast array of ready-made accessories are particularly well suited for astrophotography.

The telescope is only part of the story. You need to get a selection of fine eyepieces if you expect your scope to perform well. A virtual explosion of high-quality eyepieces has surfaced over the past few years, and advertisements for them can be found in *Astronomy* each month. You'll also want to consider simplicity of the telescope's mounting. If you absolutely do not want to do astrophotography, you can simplify your life and cut costs by getting a telescope on a so-called Dobsonian mount,

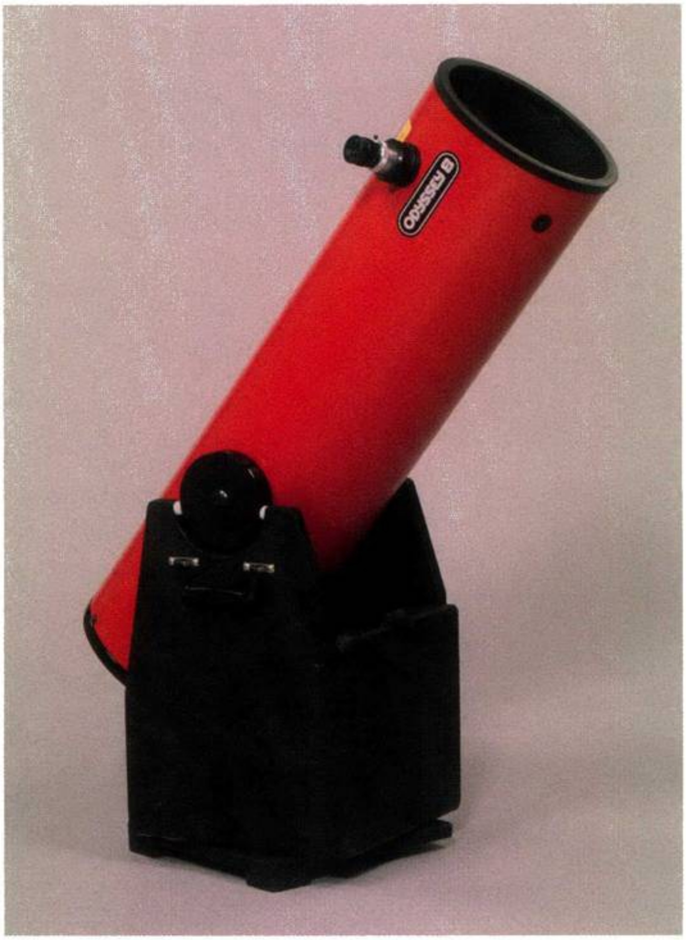
named for John Dobson, who popularized them. A Dob is an altitude-azimuth mount equivalent to a battleship gun mount. It cannot track the stars, so you'll need to nudge the scope along to keep an object centered, but its simplicity and low cost are assets if you are strictly a visual observer.

Another type of telescope mount is the equatorial mount. Rather than moving simply back-and-forth and up-and-down, equatorial mounts are aligned to the north celestial pole, a point in space very near the star Polaris. (For this reason, Polaris is often referred to as the North Star.) With the addition of a drive motor, such a mount can move the telescope tube so that whatever object is in the field of view will be followed. What's actually happening is that the drive motor is compensating for Earth's rotation. Even Dobsonian mounts can be "driven," although this takes two motors and an internal processor to keep them in sync.

Before you choose a telescope, sample a variety of telescopes at a local astronomy club star party. Read the annual telescope buyer's guide published in *Astronomy*. And ask other amateurs to share their experiences. Remember that magnification — the classic advertising hype symbol — is not the important attribute of a telescope. For almost all observing you'll be using powers of 40x to 150x. The important thing is the diameter of the lens or mirror, the telescope's aperture. You can see the Moon, planets, and hundreds of deep-sky objects with a 4-inch telescope. You can see thousands of deep-sky objects with an 8-inch telescope. As a general rule, you'll probably want to get the largest telescope you can afford as long as it is not so large that you mind lugging it around. Consider your observational interests and your level of interest in photography before deciding. It's a complex thing to determine, and a good reason to spend a few months warming up with good binoculars.



A MAMMOTH 36-INCH DOBSONIAN, built by Obsession Telescopes, approaches the practical upper limit for portability in an amateur telescope. ASTRONOMY/ALAN DYER



THE CLASSIC, SIMPLE DOBSONIAN, built on a rocker box, allows observers the most aperture for the smallest price — though it won't track on sky objects. ASTRONOMY/WILLIAM ZUBACK

silver halide and electronic chips: imaging the cosmos

Telescopes can be more than observational tools. They can also allow you to collect and store images of the sky objects you observe. Not only is it great fun to take photographs, collect electronic CCD frames, or simply sketch objects with a pencil and pad, but taken together, weeks, months, and years of collecting sky images leads to a personal inventory of your experiences as an amateur astronomer. It gives you plenty of good stuff to pull out of the closet on some cloudy night, a night in the future when you can relive the fun of the past.

keeping an observational journal

The easiest way to start your "imaging" of the sky is to keep a journal, or diary, of what you observe. Your journal can be as simple as a pad of paper on which you write down what you've seen during each observing session. Or it can be as fancy as a leather-bound book in which you note observations, make sketches, write in data for various objects you've seen, record comments on weather phenomena, and jot down anything that comes to mind about the universe at large.

Of all the ways to capture images of the cosmos, the easiest (and one of the most effective) is to sketch objects as your eyes see

AURORA BOREALIS RAINS DOWN pinks, yellows, and greens on the Cape Cod Imaging Station in East Dennis, Massachusetts on an autumn night in 2002. This 60-second exposure was taken using a 24mm lens at f/2.8 and Fujicolor Press 800 film. CHRIS COOK

them. All this requires is a pad of paper and pencils. A #2 pencil works nicely, although an art pencil like an Eberhard Faber Ebony pencil works best.

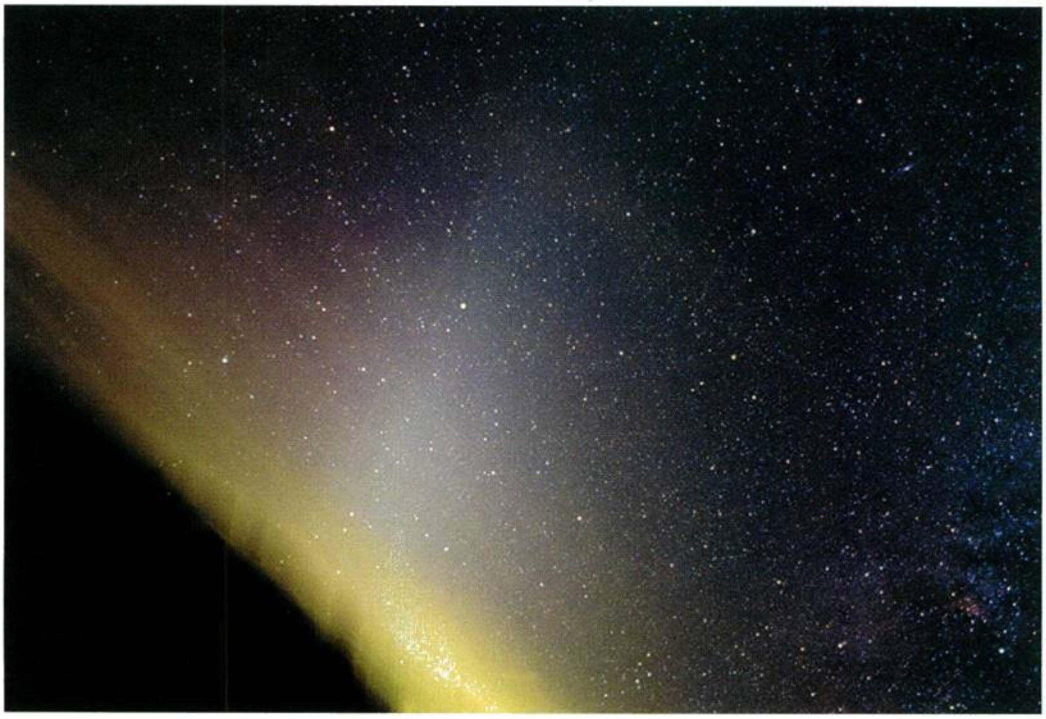
The technique is simple. First draw a circle that represents the telescope's field of view. Take the paper, pencil, and a dim red-filtered flashlight outside with your telescope. (The red color of the light is chosen because your eyes are least sensitive to red light, so it is the color least likely to ruin your eyes' adaption to the darkness. Remember, though, it must be dim. Even red light, if bright, will affect your dark adaption.) After you've set up and have an interesting object centered in the scope's field of view, simply look alternately into the eyepiece and down onto the paper. First, carefully plot the brightest stars on the drawing. Use geometric patterns and distances to gauge the placements of these stars in your circle on the paper. Now add the fainter stars, using the bright stars as guideposts to place them correctly. Finally, you can rub a small amount of graphite from the pencil onto the paper and smooth it carefully with the light touch of a moist finger to simulate the fuzzy light from a galaxy or nebula. If you're looking at a planet, draw its disk first and then, working from the poles, shade in subtle details you see on the planet. It takes a bit of practice to get good at this, but sketching is inexpensive and relatively easy to do. You'll be surprised at how rapidly the quality of your sketches improves. The most powerful benefit of sketching at the eyepiece is one unmatched by any other form of imaging: it lets you record sky objects exactly as your eyes see them.

astronomical photography with camera and tripod

Another easy way to record your favorite astronomical objects is to photograph them. Although some forms of astrophotography are tricky, getting started is a joy. The basic equipment necessary for your first astrophotos consists of a camera capable of making time exposures (one with a shutter that can stay open for long periods), a

THE MOON, SATURN, AND VENUS hang together in a triangle near the stars of Taurus in this image made July 17, 2001. California astrophotographers Tony and Daphne Hallas used a 35mm lens at f/2 for the short exposure. Saturn is upper-left of the Moon, Venus is lower-left, and Aldebaran, the eye of Taurus, is lower right.

TONY AND DAPHNE HALLAS



ZODIACAL LIGHT PIERCES CIRRUS CLOUD ► in an image captured in January 2002. The orange "star" near the top of the triangle of light is Mars in this 30-minute exposure using a Nikon 15mm rectilinear lens at f/3.5 and unhypered 35mm Kodak Pro 400 film. CHRIS COOK

lens of 28mm to 50mm focal length (the standard lens has a 50mm focal length), a roll of fast (generally 400 to 1600 ISO) film, a cable release, and a sturdy tripod.

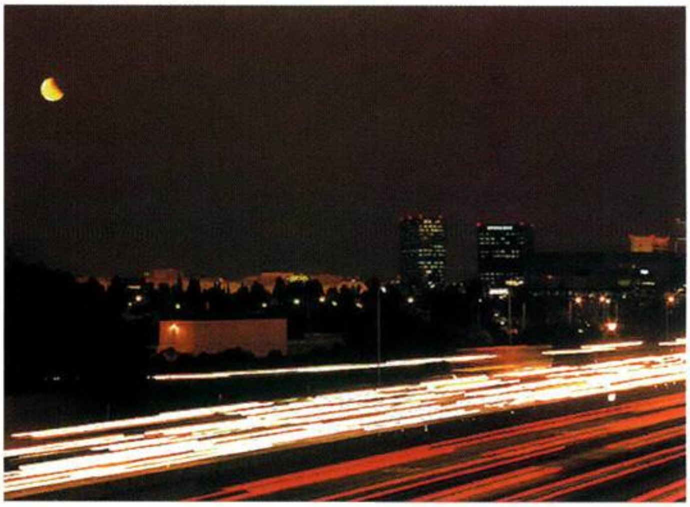
The best way to start is to set up before dark, having loaded film in the camera and attached it to the tripod. Carry the whole assembly outdoors and after nightfall aim it toward a favorite constellation — perhaps Orion in the winter or Sagittarius in the summer. Depending on your lens's focal length and where you are aiming in the sky, you can take photos of 15 to 30 seconds before Earth's rotation turns the stars into streaks. Take a number of these shots and you'll soon find yourself on the way to assembling a library of constellation photos. If you let the exposure go for longer — perhaps 10 to 30 minutes — you'll get pretty pictures of star trails. If you use color film, you'll see that many of the star trails show subtle blues, yellows, and oranges as well as stark white.

Camera-and-tripod photography is also great for capturing wide-field portraits of planetary groupings, called conjunctions. You may find the Moon hanging in the sky near a bright planet. Try exposures up to 30 seconds long of the two at dusk and you'll have a beautiful scene, especially if you compose the picture with an attractive foreground. The technique is also powerful for capturing bright aurorae.

piggybacking your camera

If you have an equatorially mounted telescope with a clock drive to track the stars, you can go a step beyond camera-and-tripod

A YOUNG CRESCENT MOON SETS ▼ into the deep orange twilight blanketing the 60-inch and 200-inch domes on Palomar Mountain, California. Chris Cook recorded this image with a Nikon 200mm lens at f/4 and Kodak Ektachrome 400 film. CHRIS COOK



A PARTIALLY ECLIPSED MOON ◄ appears tranquil and ignored as it quietly rises over the speeding and oblivious cars on the 405 freeway in Southern California. Using a fixed tripod, Chris Cook captured this image using a Nikon 105mm lens at f/5.6 lens in December 1992. CHRIS COOK

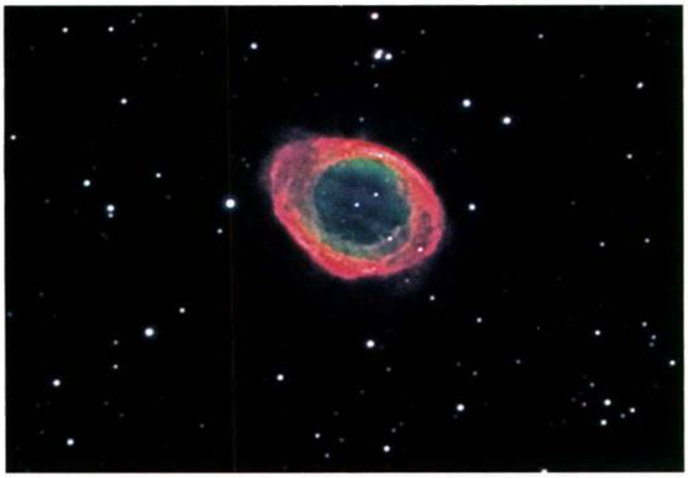
photography and take "piggyback" astrophotos. With this technique, you mount the camera and its lens atop your telescope and use the scope itself as a guiding platform to move the camera in sync with the stars. The camera rides piggyback on the scope. No longer are you bound by short exposures; now you can take pictures of much fainter objects by keeping the shutter open for periods of 15 to 30 minutes. If you properly align your telescope relative to the North Celestial Pole (see your owner's manual), your piggybacked photos will contain stars that are small dots rather than being streaked into arcs. You may also use a special guiding eyepiece that contains an illuminated reticle — dimly lit crosshairs — so that you can watch a bright star in the telescope and make minute corrections in tracking during the exposure with a drive corrector.

Many subjects lend themselves especially well to piggyback astrophotography. You might use a wide-angle lens to capture vast panoramic views of the Milky Way's star clouds and nebulae. You might want to capture bright, large star clusters like the Pleiades and Hyades in the constellation Taurus using a 50mm lens, or capture long exposure shots of constellations that record faint stars and wisps of nebulosity. You may want to employ a telephoto lens of 150mm to 300mm focal length to zero in on smaller deep-sky objects like individual clusters and nebulae, capturing them in exposures of up to half an hour. The potential is virtually unlimited, and experimentation with films, lenses, and exposure times is the

A FULL MOON RISES through clouds in the Sierras as a cold front moves in. Tony and Daphne Hallas used a 4-inch f/8 refractor for the shot.

TONY AND DAPHNE HALLAS

THE WHIRLPOOL GALAXY (M51) ▲ reveals its spiral splendor to medium-sized telescope viewers. This image was made by Rob Gendler, who used a 12.5-inch Ritchey-Chrétien scope and a 5-hour composite exposure. ROB GENDLER



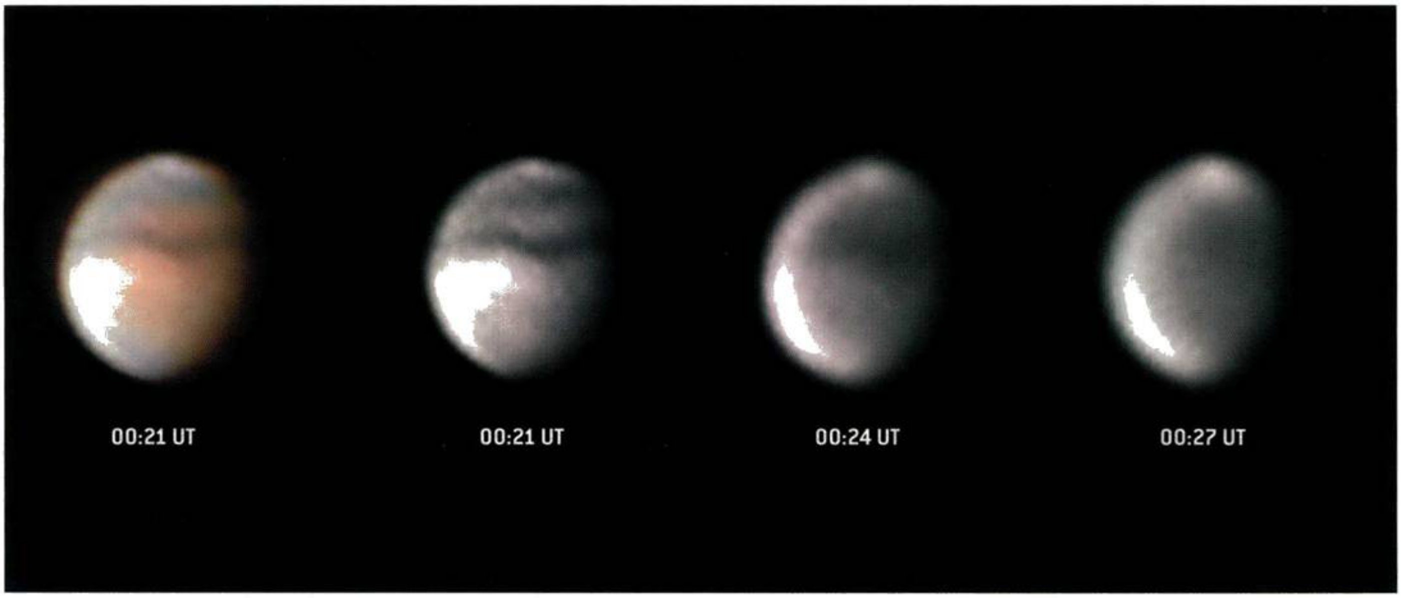
VIVID COLOR STANDS OUT in the ▶ Ring Nebula (M57) in Lyra, one of the brightest planetary nebulae for amateur telescopists. The green central region results from light emitted by doubly ionized oxygen. ROB GENDLER

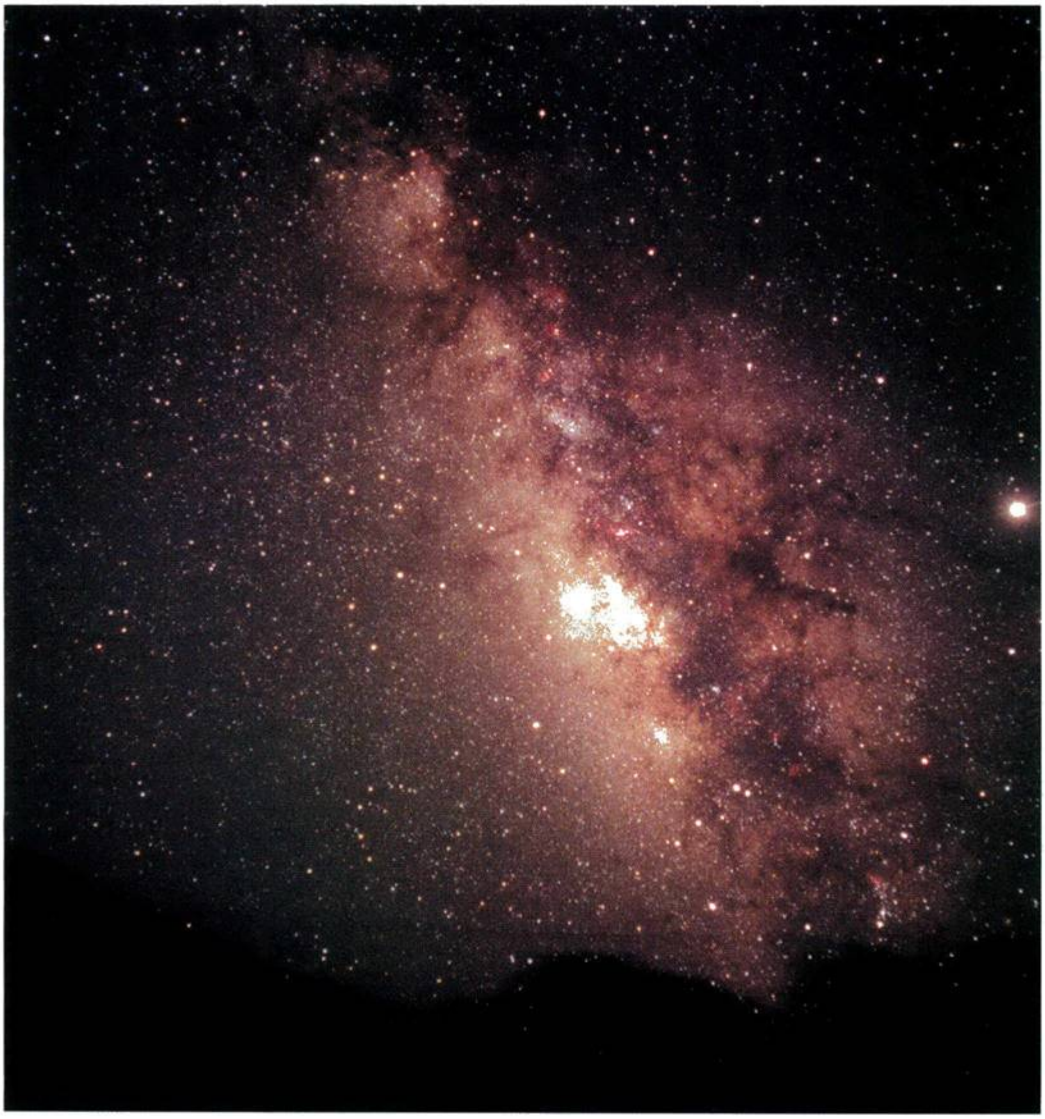
best way to achieve consistently impressive results with your particular system.

through-the-telescope photography

The trickiest type of astrophotography uses the telescope itself as a giant lens. Because the amount of sky seen in your telescope is so much smaller than with a camera lens, the result is a real closeup view of objects ranging from planets to galaxies. Sound good? The tradeoff is that a multitude of variables such as focusing and guiding become much more difficult when shooting through the scope. You now must attach the camera to the scope and focus it critically. You must guide the exposure as it occurs, meaning you have to use a good drive corrector and some type of guiding system. This might be a separate guidescope mounted on the main instrument, or a so-called off-axis guider, a small prism that diverts light from the main image into a guiding eyepiece. You'll also be shooting at a much longer focal length if you use a telescope, so exposure times must be increased to compensate for this. Polar alignment is much more critical at such long focal lengths. And because of the reduced field of view, even finding objects is somewhat more difficult to begin with.

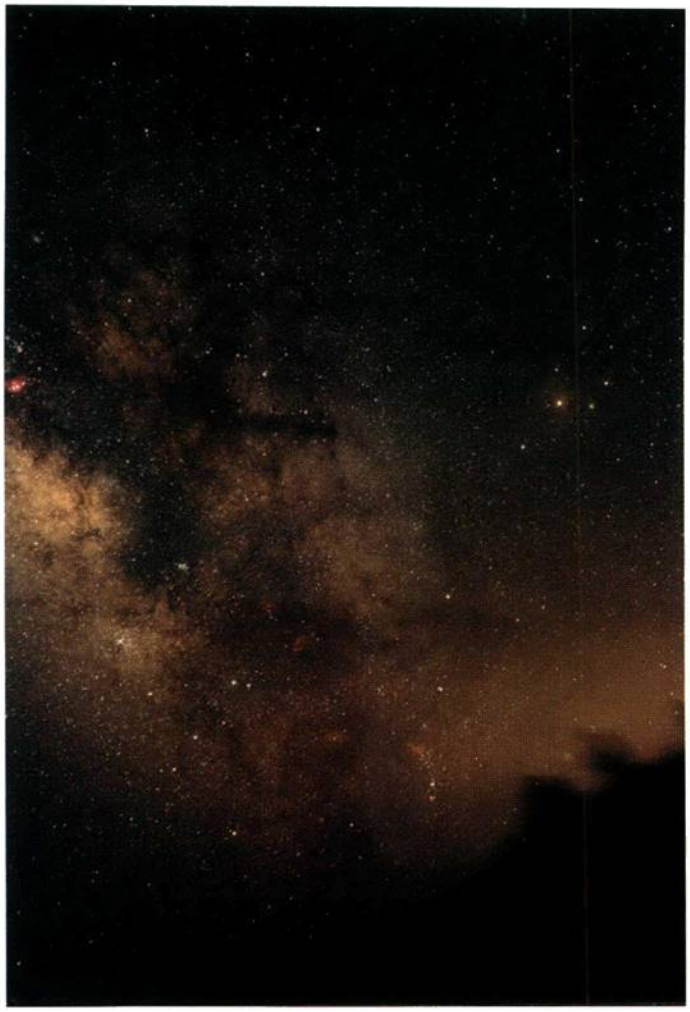
Suffice it to say that simple astrophotography, particularly the kind that you can do with camera and tripod, is the way to start. If after a few weeks or months of success you develop a real appetite for taking pictures through your scope, you can learn a lot more by reading articles on the subject in *Astronomy*. They'll provide the kind of comprehensive and informative detail you'll need to become a skilled astrophotographer behind your telescope.

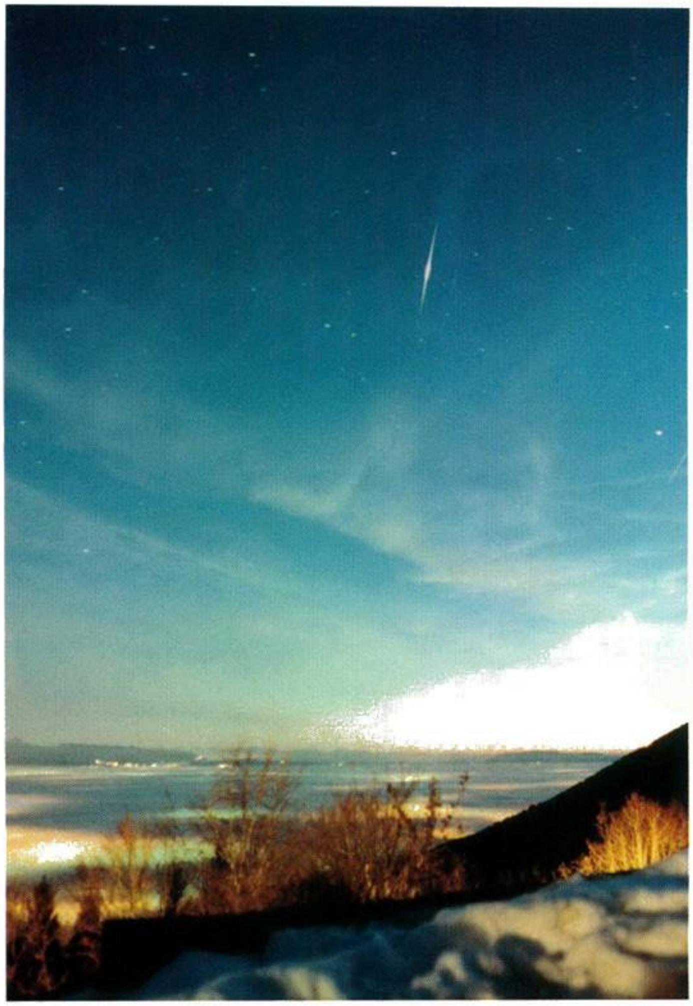


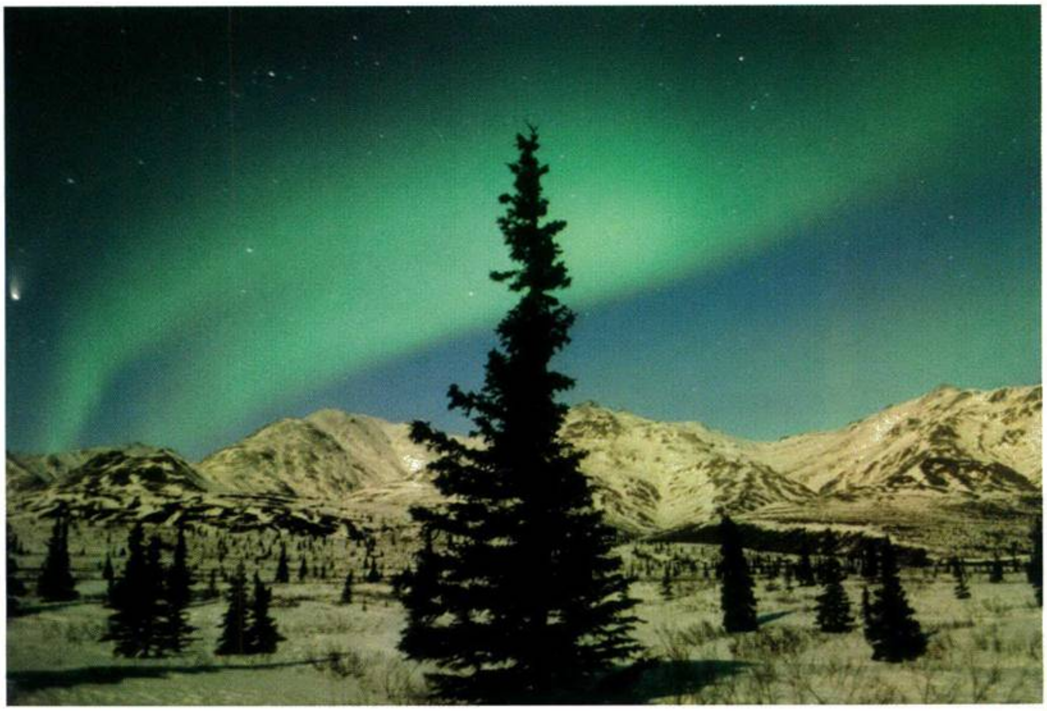


A SERIES OF MARS SHOTS ▲ shows cloud features in this composite frame made on November 14, 2001. From Florida, Don Parker recorded these images over a six-minute span with a 16-inch reflector at f/44 and a Lynxx CCD camera. DONALD C. PARKER

THE CENTER OF THE GALAXY ◄ rises slowly over the Davis Mountains of West Texas. Chris Cook captured this guided image using a 24mm lens at f/8, Kodak Ektachrome P1600 film at ISO 800, and a 20-minute exposure. CHRIS COOK



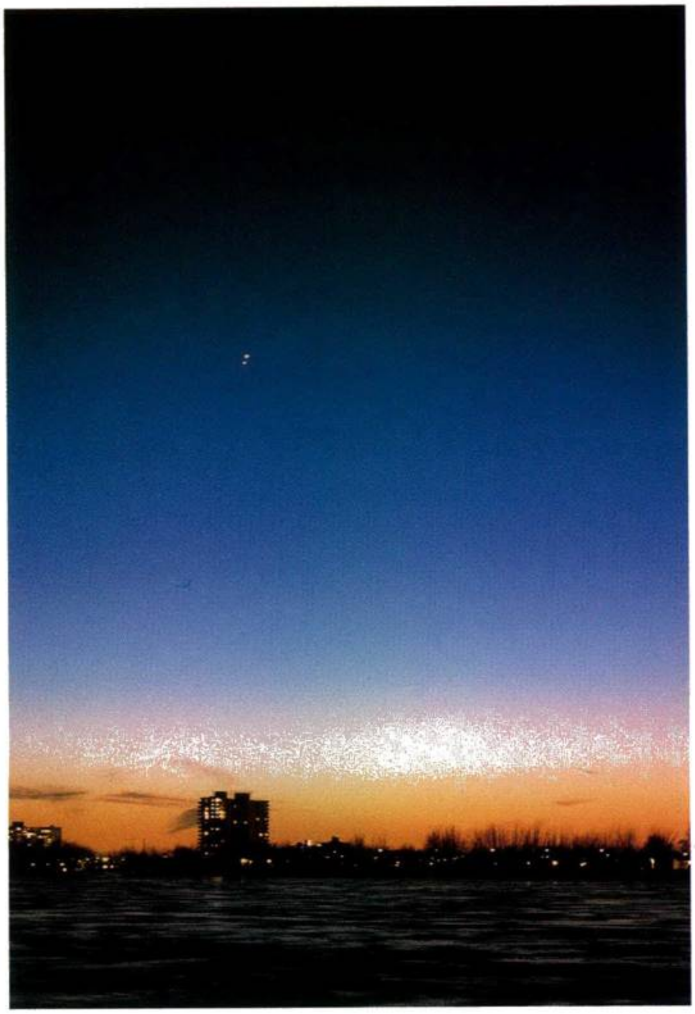


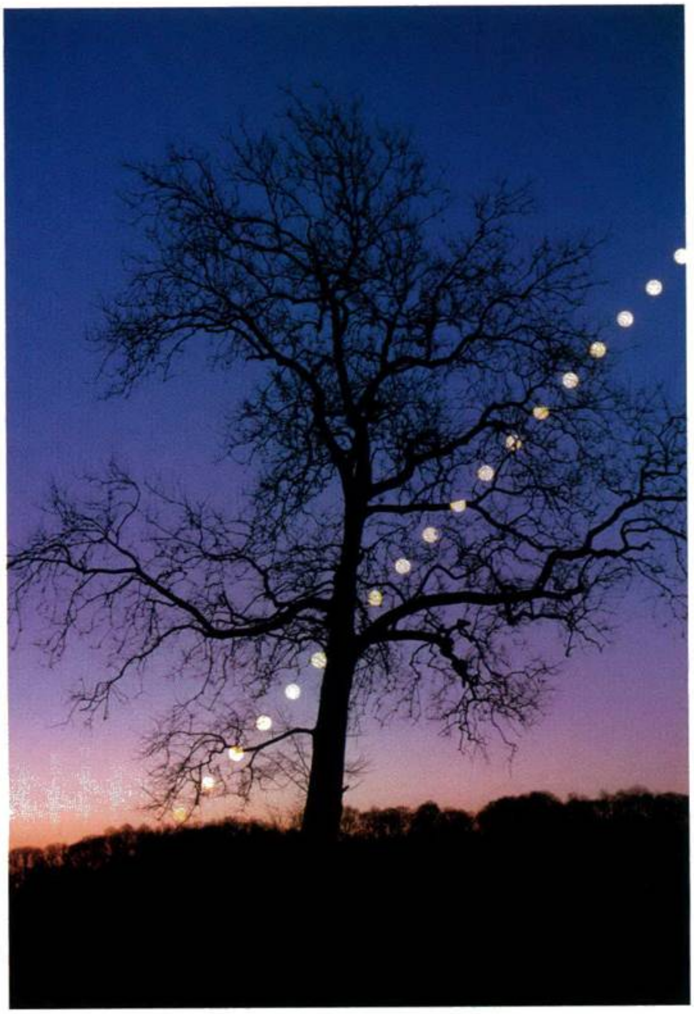


THE RICH SCORPIUS MILKY WAY ▲ hides the center of the galaxy behind thick clouds of obscuring dust. John Chumack captured this image with an 80mm medium format lens, Kodak 400 PPF film, and a 30-minute exposure. JOHN CHUMACK

FLASH! A brilliant Iridium flare, ◀ sunlight reflecting off a satellite, appears in this image of the sky shot above Geneva, Switzerland. Olivier Staiger made this image with a 28mm lens at f/2.5, ISO 800 film, and a 4-minute exposure. OLIVIER STAIGER

BRIGHT AURORAE take many ▶ forms, as with the cascading loops and arcs of this greenish show that accompanied Comet Hale-Bopp (left edge). The image was made on April 18, 1997. MICHAEL KLENSCH





THE SUN ALSO RISES as it produces spectacular dawn colors in this image by amateur astronomer Larry Landolfi. The photographer exposed his film every 6 minutes to capture this composite. ▲

LARRY LANDOLFI

JUPITER AND VENUS HANG TIGHT in a close conjunction on February 23, 1999. George Liv shot the pair over St. Laurent, Quebec, using a 105mm lens at f/3.5, Ektachrome 400 film, and a 4-second exposure. GEORGE LIV ▼

the electronic sky: video cameras, CCDs, and computers

I can remember the good old days, way back, a decade or so, when the most complex and rewarding type of astro-imaging was shooting photos through the telescope. Now a variety of electronic devices makes it possible to capture beautiful images of planets, stars, and galaxies in digital form. Rather than taking the film down to the processor (or developing it in a tank in your bathroom), amateur astronomers often use their computers or television monitors as darkrooms. The kick here is that with a CCD camera you can take lots of images relatively quickly — exposure times are often a fraction of those used with conventional films — and manipulate the image in the comfort of your study. You can also pick and choose between frames showing, for example, a planet when the atmospheric seeing is momentarily rock steady, yielding razor-sharp images of Saturn, Mars, and Jupiter. You can also use image processing software on your PC to maximize the brightness, contrast, color balance, filtration, or other aspect of your image, all nearly instantly. This capability is extremely powerful.

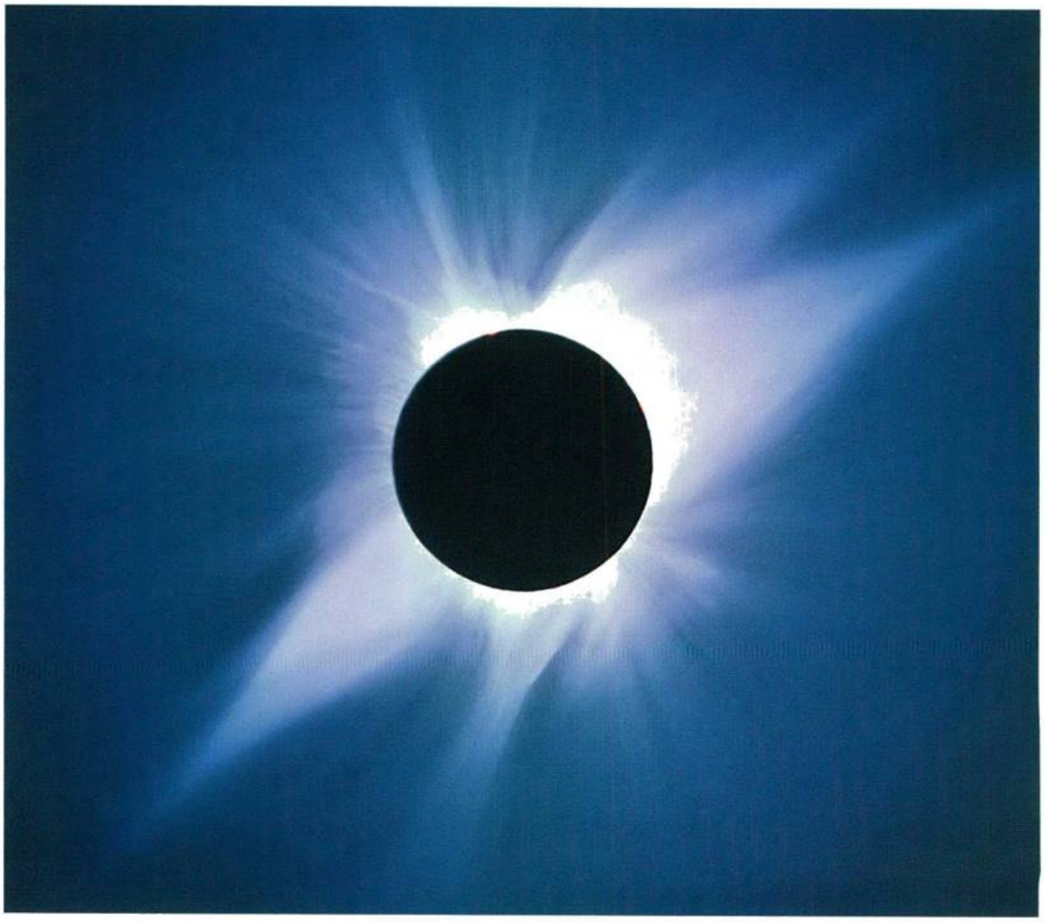
Video cameras are also useful tools for capturing astronomical images, although even with low-light-sensitive models the objects you shoot must be relatively bright. This conjures up images of family and friends first watching Aunt Irene's trip to Florida and then popping your Saturn tape into the VCR as a follow-up.

Whether you start recording notes in a journal, take a few constellation photos, sketch what you see in the eyepiece, or obtain a CCD camera and open a digital darkroom, capturing the sights of the night sky is powerfully attractive. It offers great enjoyment for the future and the capability to share observations with your family or even a large group. Try a few experiments with astro imaging — you never know where they might lead you.

dominant spheres: the Sun and Moon

Two astronomical objects completely dominate the sky. One is so bright that it blots out virtually everything else above the horizon. It is of course our own star, the Sun. By definition the opportunities to observe the Sun come not at night but during the day. The second dominant object is another solar system body, Earth's Moon. Although it is much fainter than the Sun in terms of sheer brightness, the Moon — particularly at Full phase — is so bright that it seriously impairs seeing faint objects when it is up during the night. These two dominant spheres are the key objects in our sky; one because it is the central source of energy in the solar system and the other because it lies so close to Earth.

A DEEP EXPOSURE reveals the ▼ beauty of the Sun's corona, visible at mid-eclipse in 1991. Pinkish prominences peek out on the top and bottom of the Sun's disk.
TONY AND DAPHNE HALLAS



our star the Sun

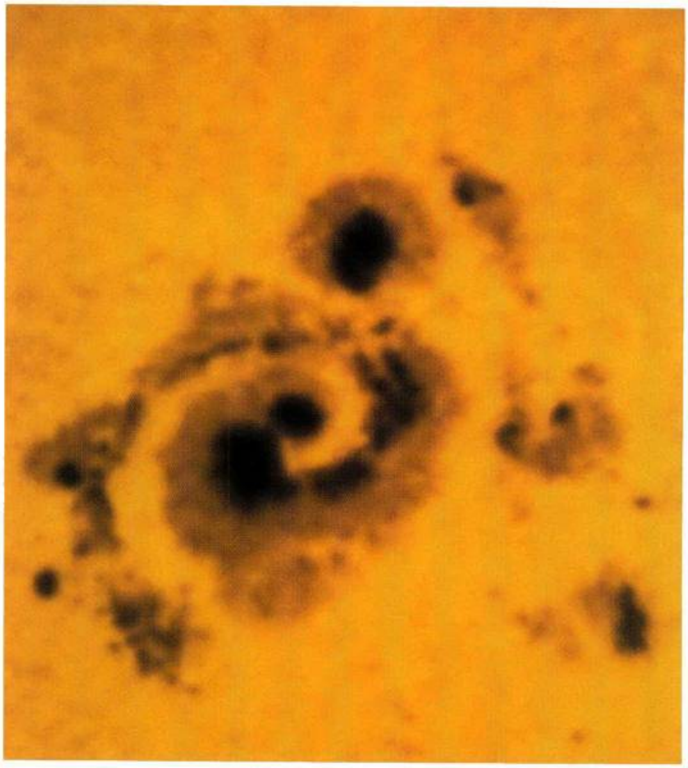
Most beginning amateur astronomers think of astronomical observing as a purely nighttime activity. Of course most objects are visible only after dark, but it can be absorbing to observe the Sun itself. It's especially enthralling to observe the Sun if we think deeply about what the Sun means to us as earthlings.

Some 4.6 billion years ago, the Sun gravitationally condensed out of a cloud of interstellar hydrogen gas and formed a sphere of high-density material. At a critical moment when enough mass was present the infant Sun blinked on, becoming a dazzling engine that fuses hydrogen atoms into helium. This process of nuclear fusion occurs in all stars, and it is the process that enables the Sun to produce copious amounts of light and heat — the necessary contributions from the present-day Sun for the sustenance of life.

Eons after the Sun ignited, uncountable chunks of debris left over from the formation of the solar system fell into orbits around it. Some of the closer material fell into the Sun and was vaporized. Much of the material some distance away from the Sun, primari-

AN ERUPTING SOLAR PROMINENCE, ► seen in the light of hydrogen-alpha emission, was captured on June 20, 1989. Prominences are clouds of gas in the inner corona visible as bright projections beyond the limb. NSO/AURA/NSF

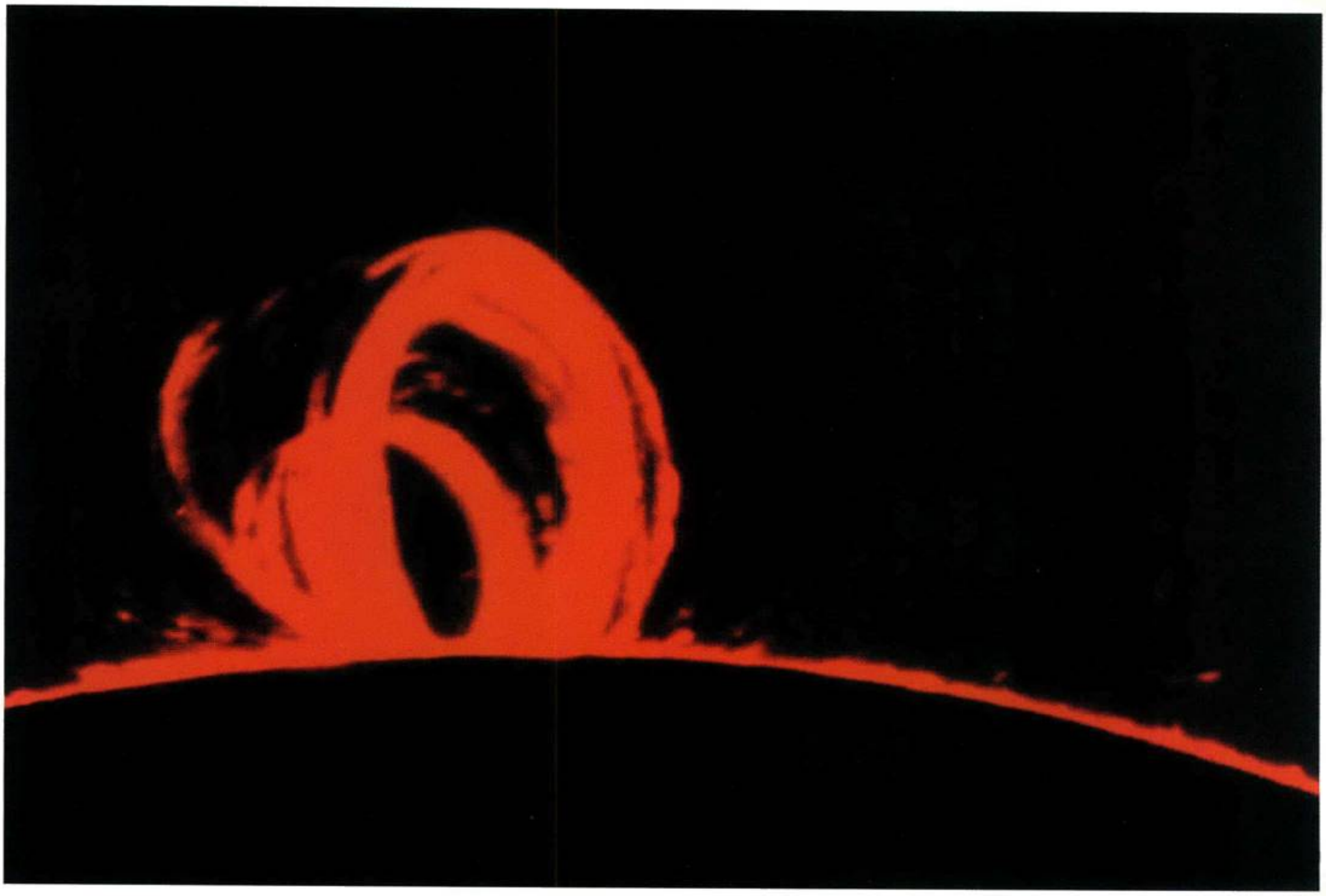
A SPIRAL-SHAPED SUNSPOT ► was captured by National Solar Observatory astronomers on February 19, 1982, using the Vacuum Solar Telescope on Kitt Peak, Arizona. This sunspot had a diameter of approximately 50,000 miles — six times larger than Earth. NSO/AURA/NSF

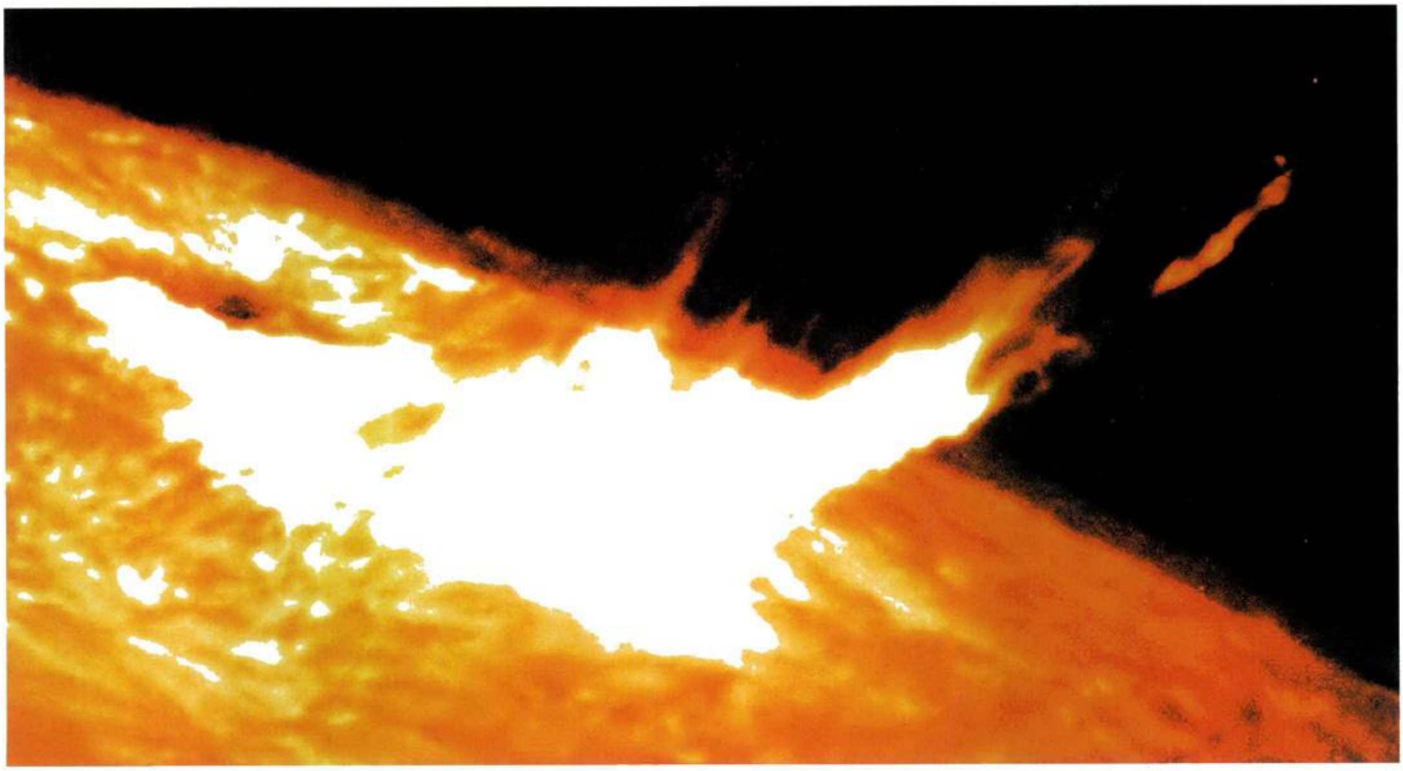


ly made of rock, gases, and ice, accreted into planets, asteroids, and comets. Chunks slammed into chunks and sent worlds careening off into orbits that eventually became stable. We are experiencing the net result of this event — minuscule as it is on a galactic scale — some 4.6 billion years after it began.

The Sun is a more-or-less average star as stars go. Stars come in much larger, hotter types and stars come in much smaller, dimmer designs. The Sun lies midway between the two extremes. However, because dim dwarfs outnumber all other stars, astronomers can say fairly that the Sun is relatively impressive in terms of energy output. The Sun measures about 1,392,000 kilometers across at its equator —108 Earths stacked side by side would be needed to fill up the distance. The Sun's mass is equivalent to

THE DISTINCTIVE LOOP SHAPE of ▼ many prominences results from strong magnetic fields bending hot coronal plasma into a loop. NSO/AURA/NSF





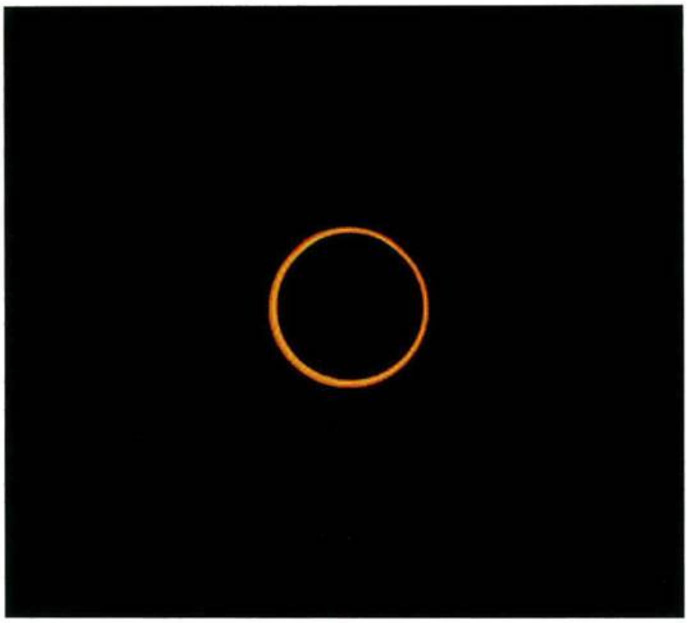
A SOLAR FLARE EXPLODES off the Sun's limb. This picture was captured by SOLIS, a special facility for solar observations. NSO/AURA/NSF, 1998

328,000 times that of the Earth-Moon system. The Sun is a yellowish-white star with an apparent magnitude of –26.8 and a surface temperature of 5800 K — hot enough to melt steel into soup. Thankfully, the Sun lies more than 93 million miles away, a distance astronomers call one astronomical unit (AU). Earth lies in just the right place for living beings: if the Sun were much more distant or much closer, the temperatures and radiation we would experience would be either too cold and too weak or too warm and too strong for living things. Although our solar system may be a rather plain one set around a run-of-the-mill star, we're fortunate that conditions aren't more exciting.

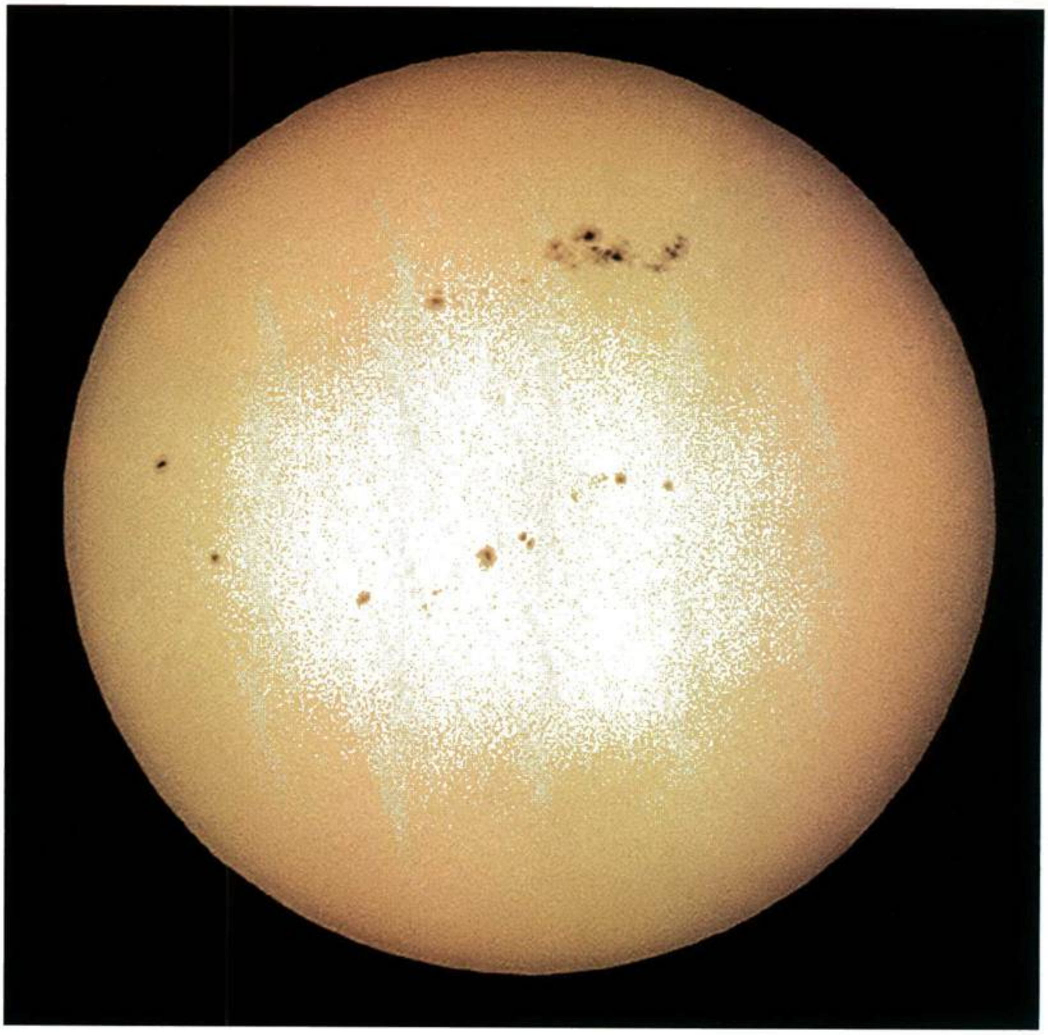
daytime astronomy: observing the Sun

It's a joy to watch the behavior of the Sun on a warm spring or summer day when the sky is a deep blue and the Sun's rays are beaming down with all of their might. Binoculars or a telescope can show a variety of phenomena associated with the Sun. However, you must be extremely cautious to view the Sun carefully and with the aid of a proper solar filter. Because of the intense radiation produced by the Sun, even a brief unfiltered look could cause irreversible damage to your eyes. You don't want to become an astronomy enthusiast only to lose your vision. So before you do any solar observing at all, become extremely knowledgeable about the safe use of a solar filter.

Several types of Sun filters exist. The best type is an aluminized glass solar filter made to fit over the front end of the binoculars or telescope. These filters are fairly expensive, and a more affordable alternative is an aluminized mylar-plastic filter that



A CLASSIC RING OF FIRE results from this 1994 annular solar eclipse. Chris Cook captured this image of the Moon eclipsing the Sun using his 4-inch f/5 Tele Vue Genesis refractor telescope. He used Fujichrome Velvia 50 film and a $1/125$-second exposure. CHRIS COOK



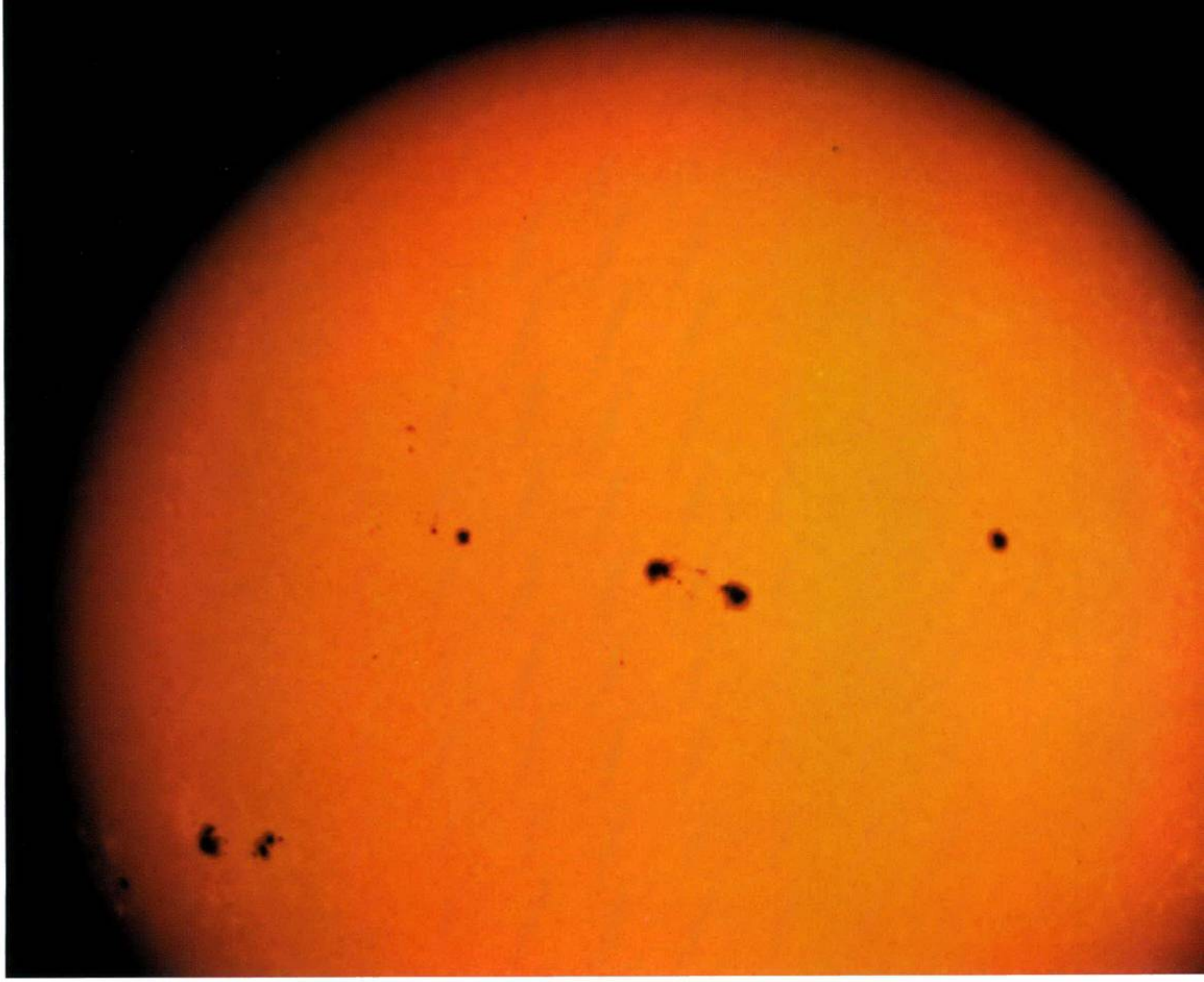
THIRTEEN EARTHS could fill the area occupied by a giant sunspot (upper right). Chris Cook shot this spot with a Nikon Coolpix 800 digital camera and a Thousand Oaks Optical Type 2+ filter. CHRIS COOK

similarly fits over the front aperture of the binoculars or telescope. Several brands of filters exist and can be found in advertisements in *Astronomy*. Do not use solar filters that fit into telescope eyepieces. These are dangerous because they allow intense radiation to enter the telescope full force. Eyepiece solar filters can crack or break suddenly, instantly blinding you. And that's not to mention the damage the intense heat can do to your scope's optics. Make sure that the proper solar filter you use securely fits onto the telescope so that no accident can happen, and be sure to cover any unfiltered optics — like a finder telescope — that someone might mistakenly peek through. In addition to optical solar filters, several companies produce hydrogen-alpha solar viewers. These devices are expensive but offer incredible views of solar prominences, flares, and a lower level of the Sun's atmosphere called the chromosphere.

You've set up your scope on a sunny day and want to do some Sun viewing. What are you going to look at? At first glance with the naked eye the Sun might seem a steady, unchanging disk of light. However, it is actually a dynamic, changing star with variable light output, sunspots, solar flares and prominences, and active regions called plages, faculae, and filaments. Moreover, on occasion, the Moon passes in front of the Sun's disk and causes a solar eclipse, one of the most breathtaking sights in all of nature.

Sunspots are the easiest type of solar activity to view. The Sun undergoes an 11-year cycle of activity so that at times of great activity the Sun's surface is far more "spotted" than other times. A filtered telescope aimed at the Sun more often than not shows a few sunspots, and occasionally sunspots are large enough to be visible in binoculars or even with the unaided (filtered) eye. If you are so inclined, grab your pencil and paper and make a series of sketches of sunspots. Once each clear day for a month will cover an entire solar "day," that is, one complete rotation of the Sun. This project will make you a better, more detailed observer and also demonstrate to you the Sun's rotation as you observe how sunspots move across the solar disk.

Sunspots are magnetic storms on the Sun's surface, regions of



cooler temperatures where a magnetic field breaks through the surface (called the photosphere) and towers above, streaming radiation into space. Sunspots usually occur in groups, and are often preceded by faculae, whitish regions of superheated gas. An intensely active solar storm can produce a prominence — a loop or burst of gas that rises over the Sun's surface. These are visible only when they occur on the Sun's limb edge and through a hydrogen-alpha filter. Solar flares are energetic blasts of gas that may last for hours or only a few seconds. Although some have been visible in white light, these too are best viewed at the hydrogen-alpha wavelength.

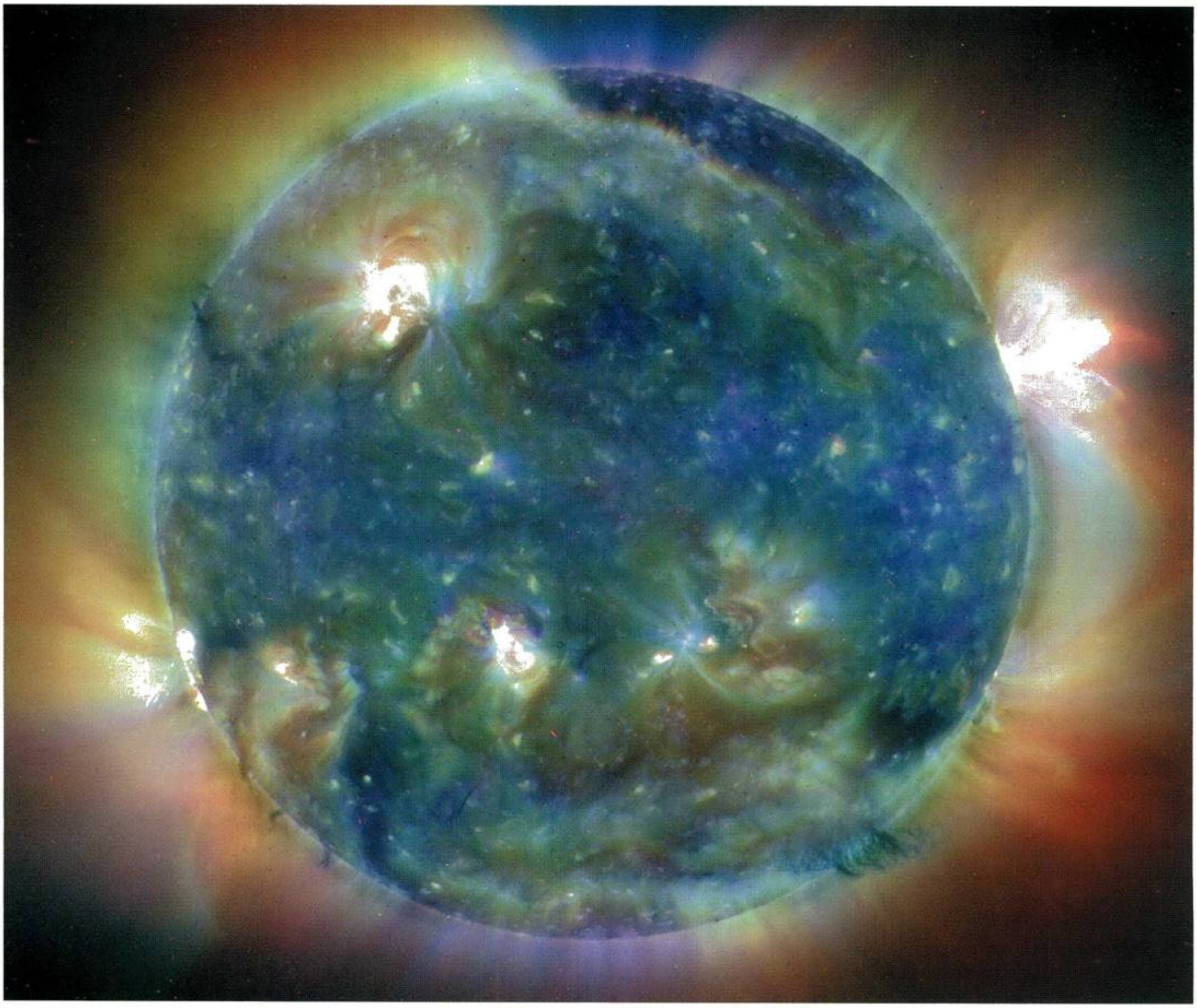
Check *Astronomy* for upcoming eclipses of the Sun. You often have to travel some distance to see one, but if you do it will stick with you for a lifetime. Three basic types of solar eclipses occur: total, partial, and annular. The differences simply reflect the orbital geometry of the particular time when an eclipse takes place. That eclipses occur as dramatically as they do is a freak accident in that the Moon's disk as we see it in the sky is almost exactly the same size as the Sun's. Hence, when the Moon passes in front of the Sun, it briefly covers the Sun. A total eclipse is a "direct hit," when the entire Sun is blocked by the Moon. This enables astronomers to view the magnificently beautiful corona, the Sun's outer atmosphere, which is usually overwhelmed by the glare from the Sun's surface. A partial eclipse happens when the Moon doesn't pass directly in front of the Sun but covers only part of it. An annular eclipse occurs when the Moon is relatively distant in its orbit, nearly covering the Sun but leaving a thin ring (the Latin word for "ring" is *annulus*) of bright sunlight around the Moon. Observe a solar eclipse or simply sunspots for several days and you might find yourself turning into a daytime astronomer.

a battered, barren world

An object of romance and wonder for ages, Earth's Moon is the dominant object of the nighttime sky (and often is also visible during the day). Because it lacks an atmosphere and active weather phenomena that resurface planets like Earth, the Moon is a stark contrast to the richness of Earth.

TWO LARGE SUNSPOTS appear close together in the center of the Sun's disk. This picture was taken with the White Light Patrol Camera at the Hilltop Dome facility of the Sacramento Peak Observatory.

NSO/AURA/NSF



A GLOWING, TIE-DYED SUN results from Extreme Ultraviolet Imaging Telescope images combined from three wavelengths. SOHO/EIT CONSORTIUM

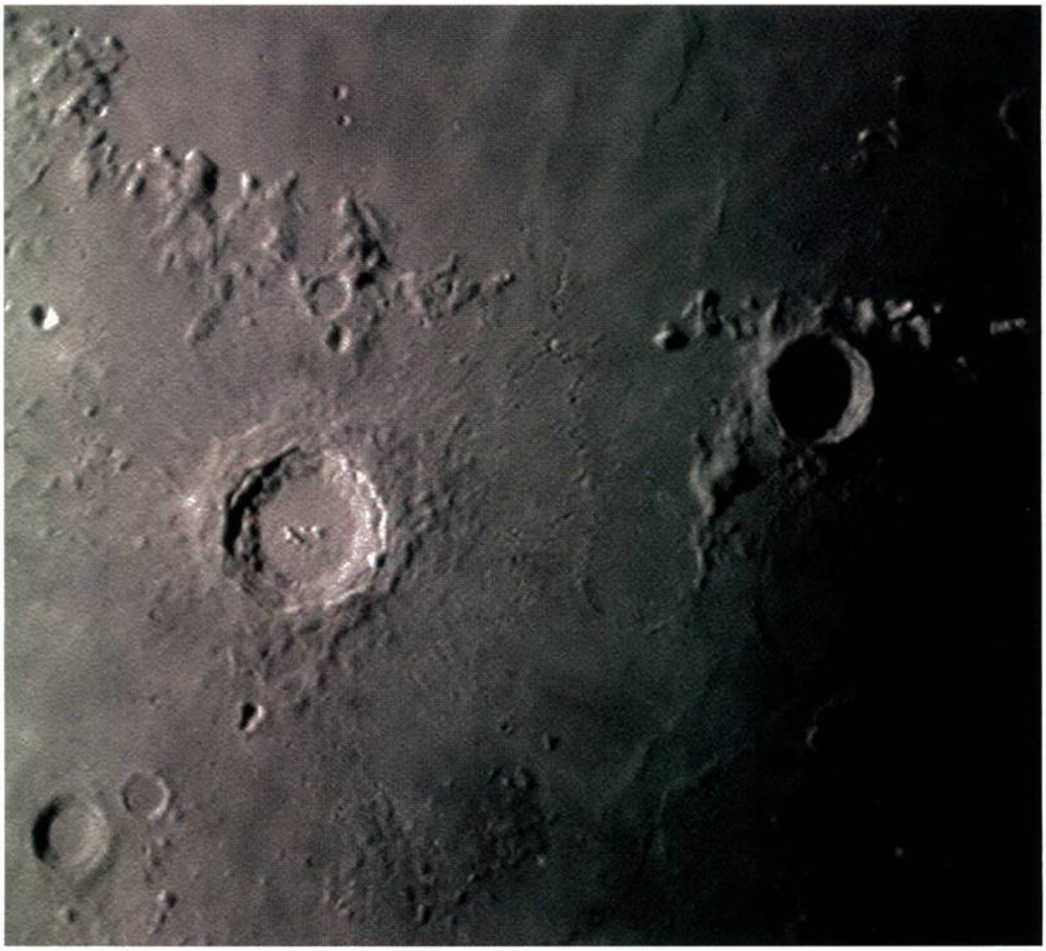
The Moon's barren emptiness and heavily cratered terrain hearken back to the early history of the solar system. Earth too has survived heavy periods of bombardment from asteroids and meteorites (and Earth will be struck in the future, too!), but Earth's resurfacing has hidden most of the scars of the past.

Collisions have played a major role in shaping the surfaces of planets, but in the case of Earth and the Moon, they played an even larger role. The leading hypothesis on the Moon's formation is that a huge collision between a Mars-sized body and Earth blasted into space the material that accreted into the Moon.

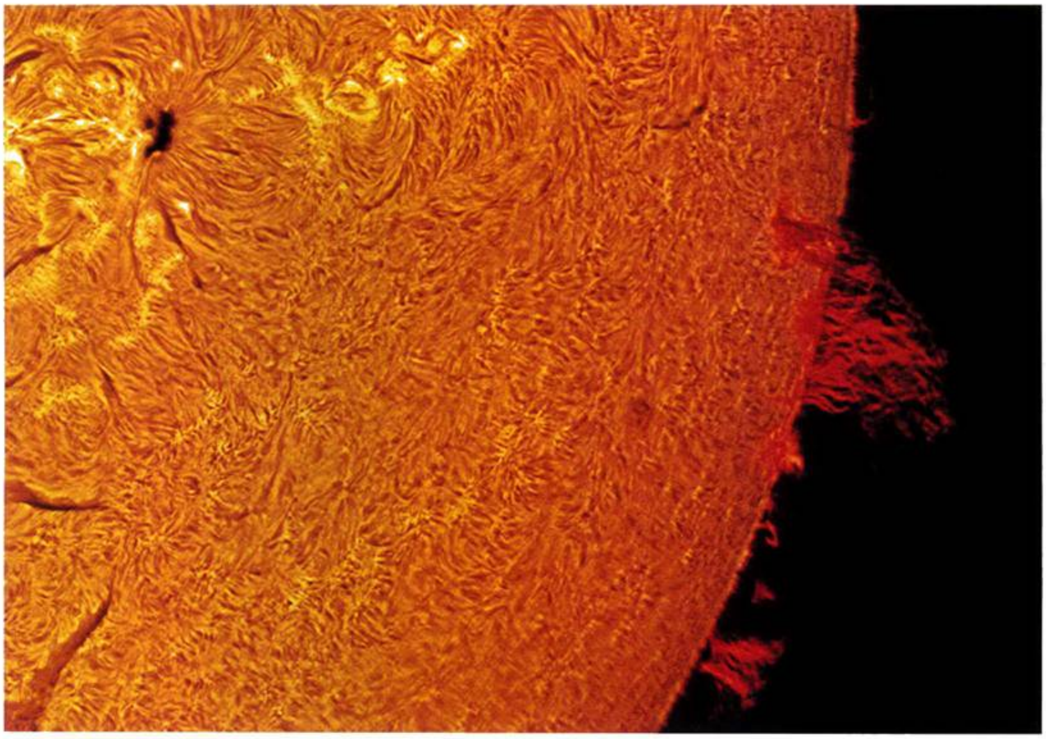
Most satellites in the solar system are relatively small compared with their parent planets. Yet the Moon is extremely large relative to Earth, making it a peculiar standout. The Moon consists of a core some 500 kilometers in radius surrounded by a mantle 1,200 kilometers deep and a crust spanning some 60 kilometers. Earth measures 12,756 kilometers across and the Moon spans 3,476 kilometers. The Moon orbits Earth much like the planets orbit the Sun, in a slightly elliptical path. In its monthly orbit, the Moon comes as close as 363,300 kilometers and is as distant as 405,500 kilometers. Because of the physical geometry of the Moon, Earth, and Sun, we see a progression of phases of the Moon as it orbits about us. The lunar cycle begins at New (dark), moves through crescent phases, to First Quarter (one half lit), waxing gibbous, Full Moon (fully lit), waning gibbous, Last Quarter (one half lit), crescent, and back to New. We've already mentioned the coincidence that the Sun and Moon are nearly the same size in the sky, which allows spectacular eclipses. By another peculiar coincidence — the equal length of time of the Moon's rotational period and its period of revolution — the Moon always presents the same face toward Earth. The far side of the Moon has been explored only by spacecraft.

exploring the Moon with a small telescope

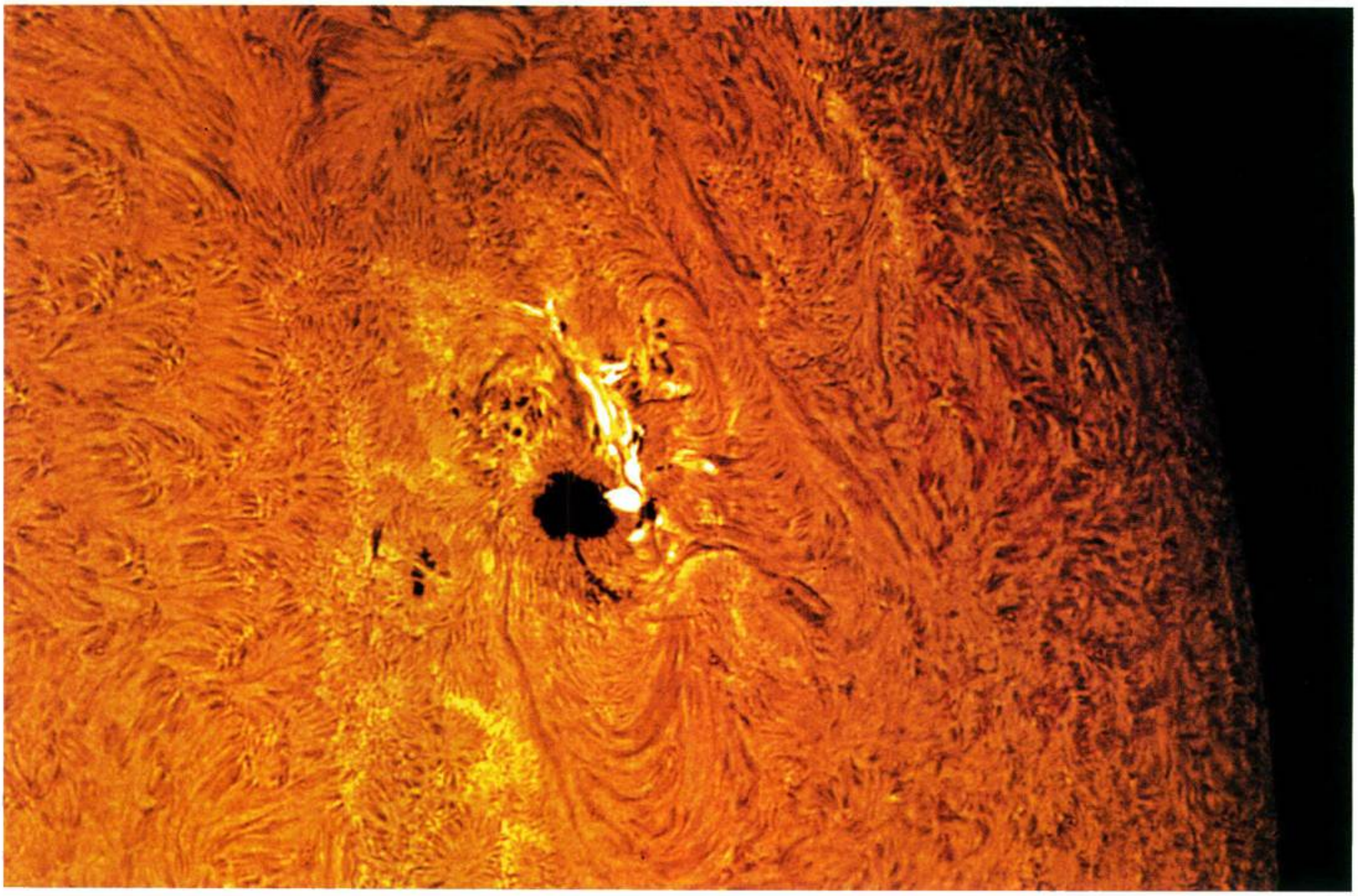
Observing the Moon is one of the easiest and most rewarding activities you can do with a small telescope. The Moon is bright, easy to find, has a large, varied surface, and looks impressive when viewed through practically any telescope — or binoculars, for that matter. To the naked eye the Moon appears as a cream-colored disk apparently spotted with dark areas, the markings that form the "man in the Moon." These are maria (Latin for "seas"), named so because they are lunar lowlands that were mistaken for actual seas by early observers. Including Mare Fecunditatis, Mare Crisium, Mare Tranquilitatis, Mare Serenitatis, Mare Imbrium, Mare Nubium,



THE GREAT CRATER COPERNICUS [in center of photo] appears ringed by a high rim and punctuated by central mountain peaks. Members of the Apollo 12 crew collected material from Copernicus that was later dated at 850 million years old. CHRIS COOK



A BLAZING COMPOSITE SUN shot in hydrogen-alpha light reveals tendrils of gas astride the Sun's limb as well as roiling regions of gas across its face. This composite was created by amateur astronomer Jack Newton. JACK NEWTON



A SUNSPOT STANDS ALONE in hydrogen-alpha light as imaged by amateur astronomer Jack Newton. Sunspots are routinely visible in properly-filtered backyard telescopes. The bright white areas are surface features known as plage flares. JACK NEWTON

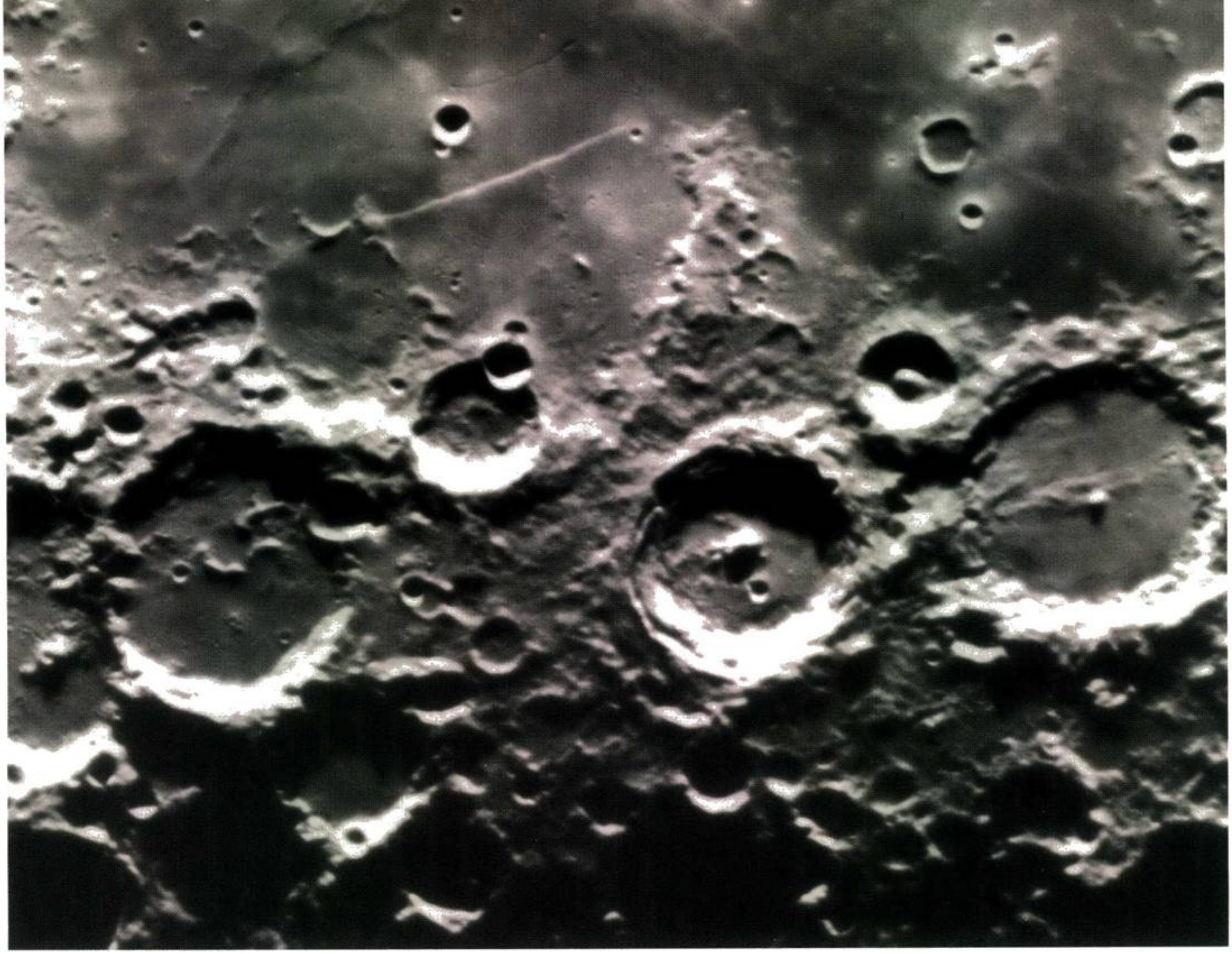
Mare Humorum, and Mare Frigorus, these areas are indeed lowlands. But instead of being seas, they are formations into which lava oozed and cooled.

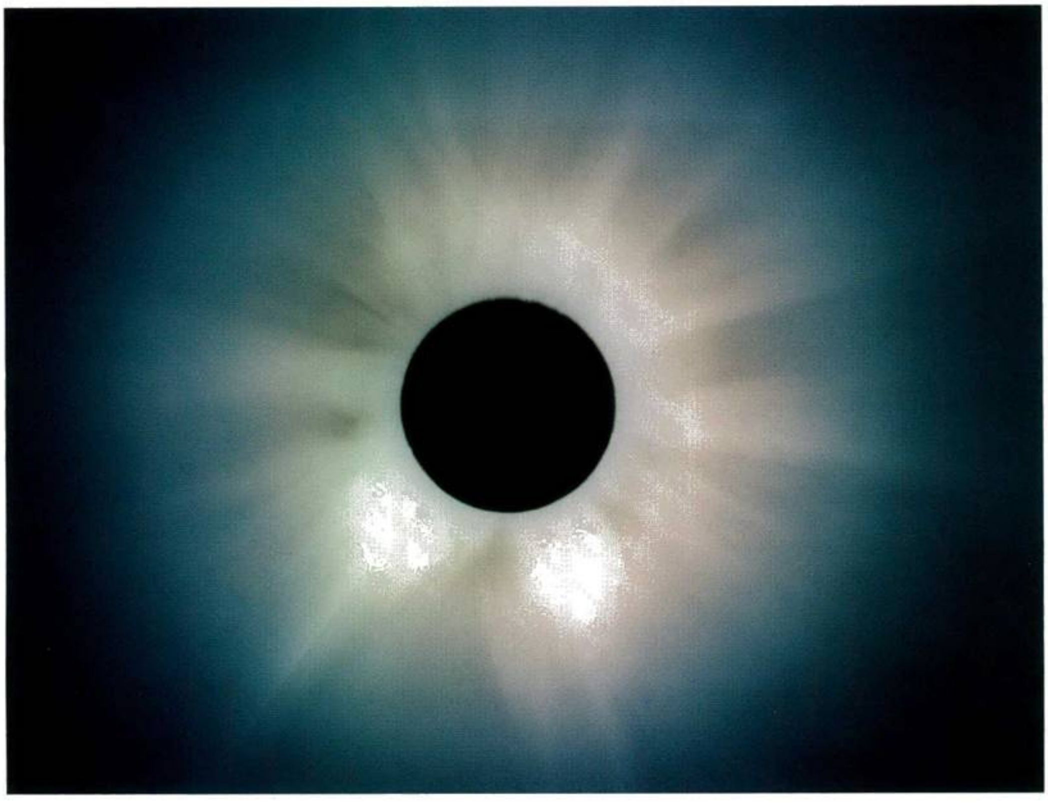
The most striking features of the Moon in a small telescope are a number of prominent craters. Perhaps the finest is Copernicus, located northwest of the center of the Moon's disk and conspicuous for its prominent system of rays. As you look at a crater like Copernicus (remember, the best time to observe a crater is when it's near the terminator), note how the sunlight illuminates the central mountain peak inside the crater. Another crater with a bright system of rays is Tycho, in the south-central part of the disk. South of Tycho lies Clavius, a large, eroded crater measuring 230 kilometers across. You'll also note a prominent pair of craters near the center of the Moon's disk. These are Hipparchus and Ptolemaeus. East of this pair stands a chain of three prominent craters called Theophilus, Cyrillus, and Catharina. These are but a few of the best craters on the Moon, of which even the smallest telescopes will show hundreds.

As you observe the Moon over the cycle of a month, return to some old friends you've looked at before and compare. You'll be amazed at how the view of craters, plains, and other features changes as the angle of sunlight changes. Some of the features look completely different.

The Moon is a steady, reliable companion in the night sky. It's there every month waiting to be observed. Yet the Moon undergoes occasional special events. When Earth passes directly between the Moon and Sun, we see a lunar eclipse — Earth's shadow cast onto the disk of the Moon. Lunar eclipses can be spectacular because the Moon appears to fade out and often dramatically reddens in color. Partial lunar eclipses occur when Earth's shadow covers only a part of the Moon. Total lunar eclipses — the most dramatic kind — happen when Earth's shadow covers the entire Moon — a "direct hit."

Even when it isn't eclipsed, the Moon dominates the night sky just as the Sun, our star, dominates the daytime sky. Because of their great brilliance and importance in our lives, the Sun and Moon are astronomical objects that are central to anyone's observing programs. Make sure you check them out at least occasionally, and remember to observe the Sun only under safe conditions with a proper filter.





LUNAR CRATERS Alphonse and ▲ Arzachel, as well as Rima Birt, stand out in this closeup of the Moon's surface. Hundreds of lunar features can be explored with small telescopes. GÉRARD THERIN

THE SUN'S CORONA blossoms ◄ in this image taken at the June 21, 2001, total eclipse from Lusaka, Zambia. Alberto Levy used an 80mm refractor at f/14.3, Fujicolor NPC-160 film, and a 3-second exposure. ALBERTO LEVY

solar system wonders: Mars, Jupiter, and Saturn

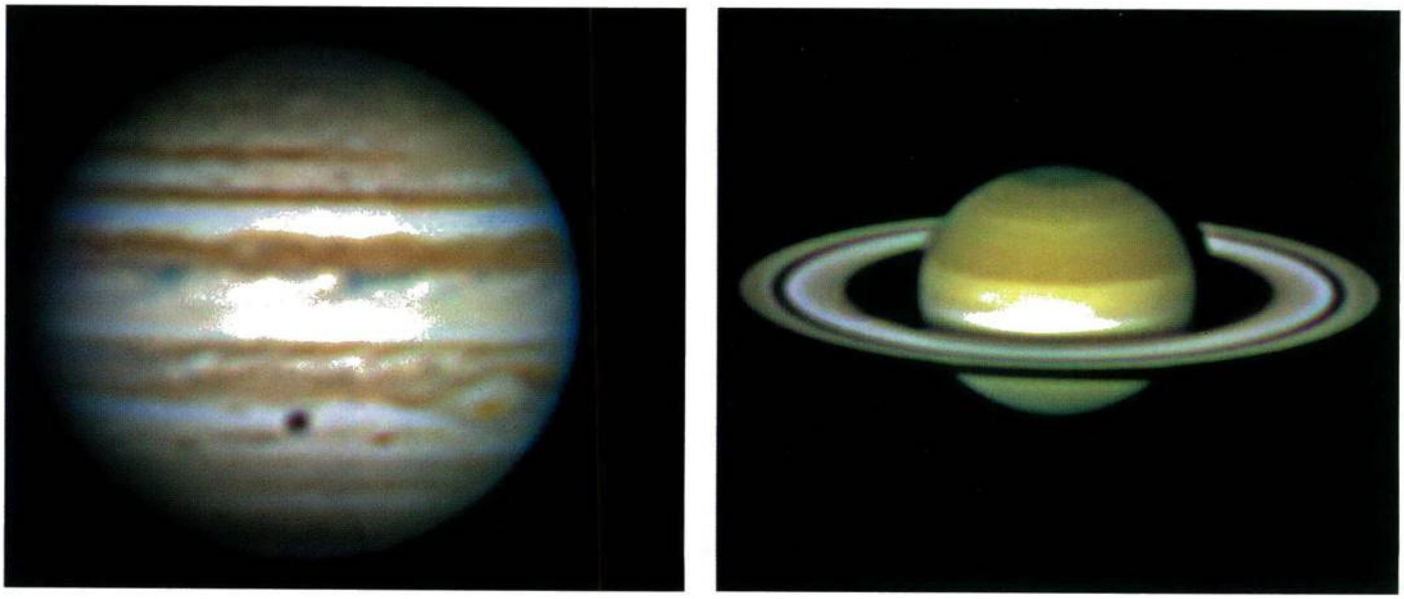
Of the eight planets in the solar system visible in telescopes, three stand out as spectacular. More than their brethren, Mars, Jupiter, and Saturn offer unparalleled detail to observers equipped with small scopes. Particularly at times of opposition every two years, the disk of Mars grows to a relatively large size. This enables backyard astronomers to see the planet's bright white polar ice caps and a number of dark features on the Red Planet's surface. Always relatively large in the eyepiece, Jupiter offers detail in its subtle banding and ceaseless show of orbiting moons. Saturn is perhaps the most breathtaking sight of all in backyard telescopes. Its orange color and sharply-defined rings inspire virtually everyone who sees it. Saturn is the reason many of today's amateur astronomers entered the hobby.

Each of these wonders of our solar system is a "must" object — something you must definitely look at and enjoy when they are visible. Yet beyond their claim to startling beauty Mars, Jupiter, and Saturn have little in common. Although all three belong to the Sun's family, they are distinctly different worlds with very different compositions.

the red planet

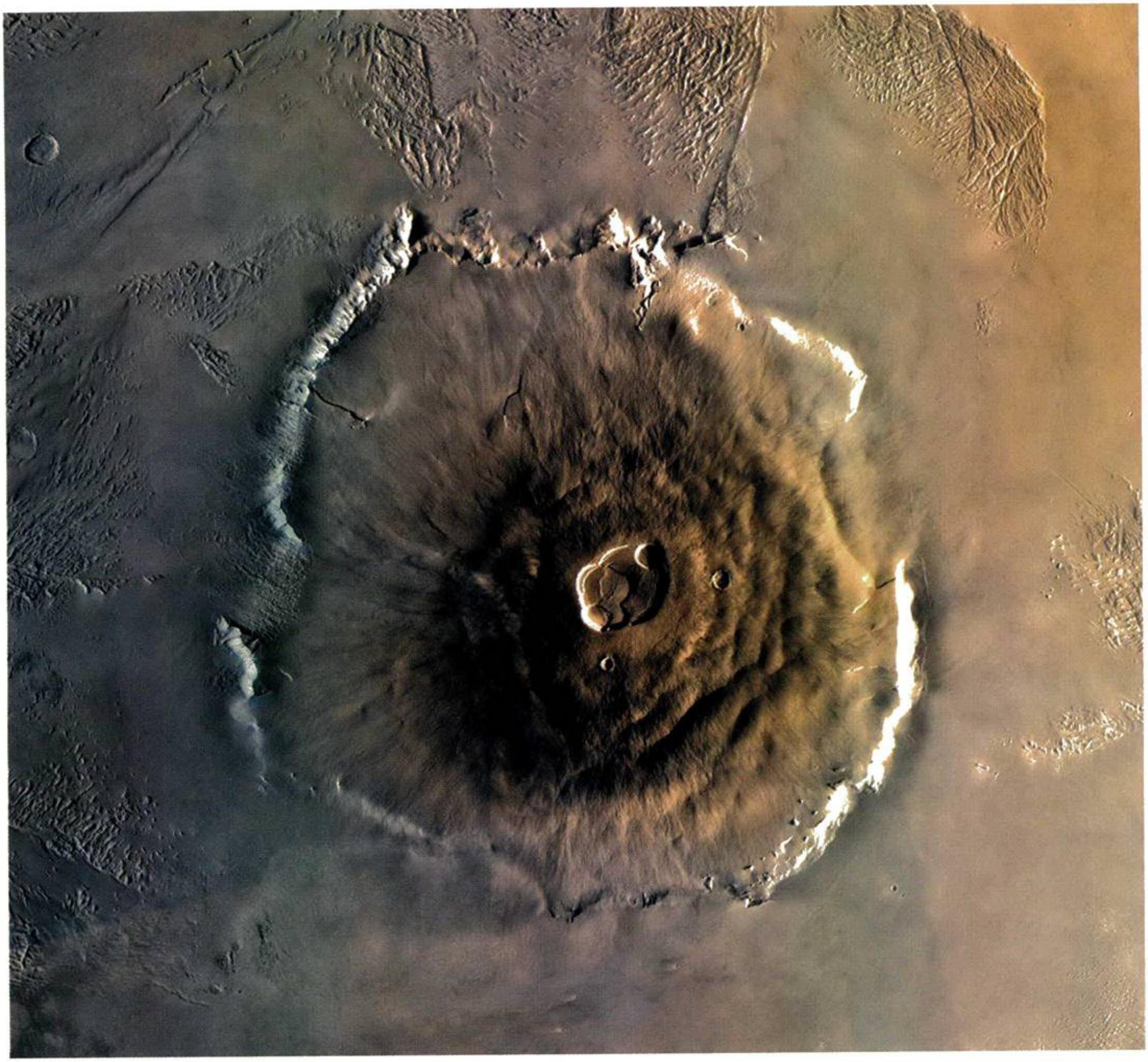
The fourth planet from the Sun, Mars measures 6,794 kilometers across, about half the diameter of Earth. The martian "year" lasts 687 days, during which Mars orbits the Sun at a distance of between 1.4 and 1.7 astronomical units. Long a favorite of romantic, mystical, and speculative stories, Mars does not harbor intelligent beings or even remnants of canals, as proposed by the nineteenth-century astronomer Percival Lowell. However, the Red Planet, so called for its ruddy color, does have one of the most unusual histories in the solar system.

Mars is a terrestrial planet with a composition much like Earth's. It has a nickel-iron core surrounded by a rocky mantle and a thin crust that we see as its surface. Mars' thin atmosphere is very different from Earth's: it consists chiefly of carbon dioxide with small amounts of nitrogen, argon, oxygen, water vapor, carbon monoxide, and so on. Martian



GIANTS OF THE SOLAR SYSTEM, Jupiter and Saturn are the favorite planets for many backyard observers. The Subaru telescope captured Jupiter's Great Red Spot (bottom right) and the celebrated rings of Saturn, along with the dark Cassini Division.

SUBARU TELESCOPE, NAOJ



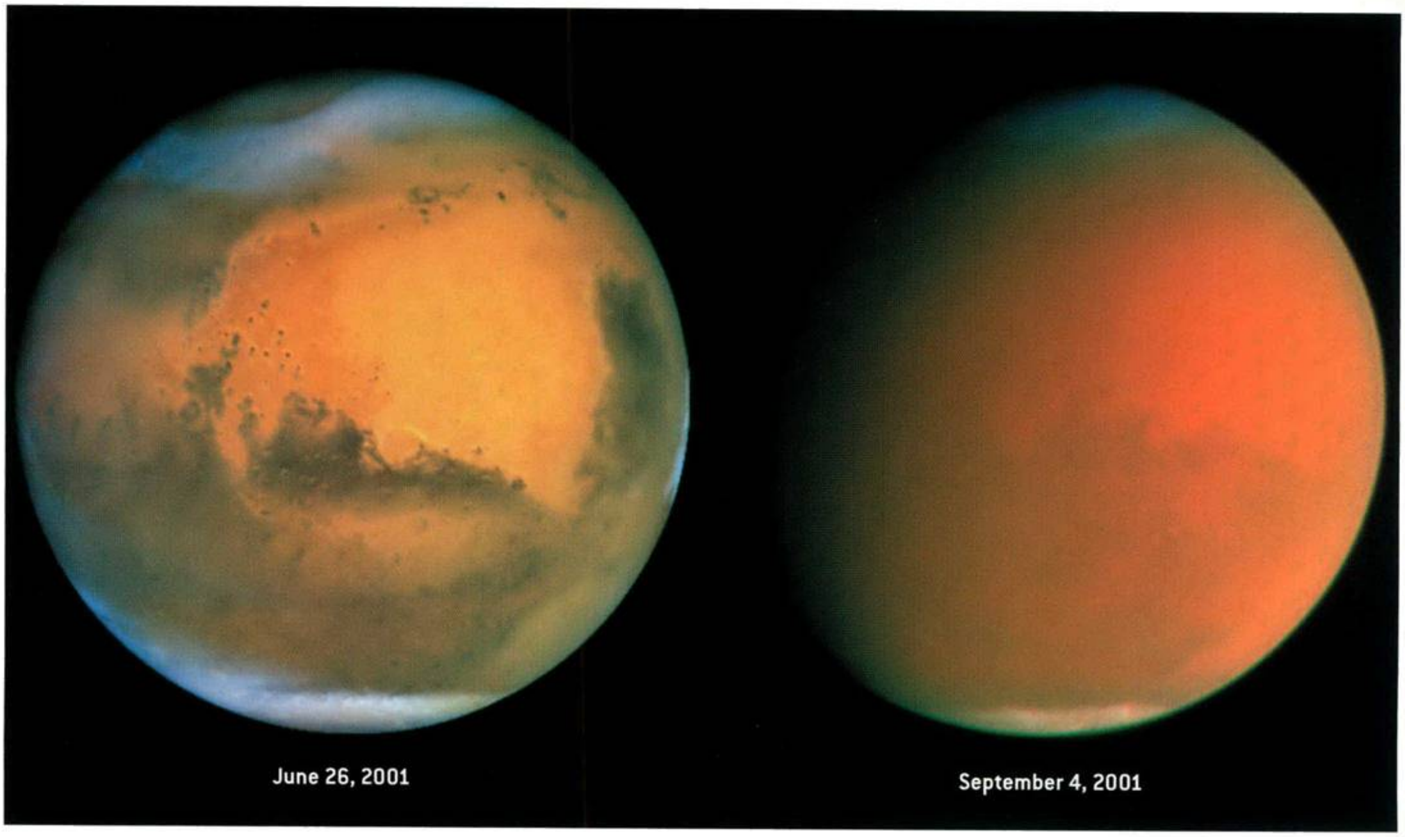
temperatures typically stay below the 0° C mark during the afternoons and at night plummet to −100° C. Although Mars wouldn't be very hospitable to human visitors, it is by far the most earthlike environment of all the planets in our solar system.

Today Mars is a very cold, dry planet. But long ago Mars was a warm, wet planet. Evidence exists for martian glaciers, demonstrating that huge amounts of liquid water and snow once existed on the planet. During the so-called Martian Ice Ages, the planet's atmospheric activity was substantially different and may even have supported the conditions for the formation of basic self-replicating organic molecules, the earliest forms of life.

Mars has two small potato-shaped moons, Phobos and Deimos. Discovered in 1877, the moons span 26 by 18 km (Phobos) and 16 by 10 km (Deimos). Their odd shapes are easily explained: Phobos and Deimos are former asteroids that were captured long ago by Mars's gravity and locked into close orbits about the planet.

The visibility of detail on Mars varies considerably depending on where Earth, Mars, and the Sun are in their respective orbits. Martian oppositions, times when the planet is opposite the Sun in the sky and is best placed for observing, occur about every two years. Typically, Mars measures

OLYMPUS MONS LOOMS over the surrounding landscape in this Viking 1 Orbiter mosaic. Olympus Mons is Mars's largest volcano; its base spans nearly 400 miles and its rims stand 28,571 feet above the surrounding plains, making it nearly as tall as Mt. Everest. NASA/JPL



June 26, 2001

September 4, 2001

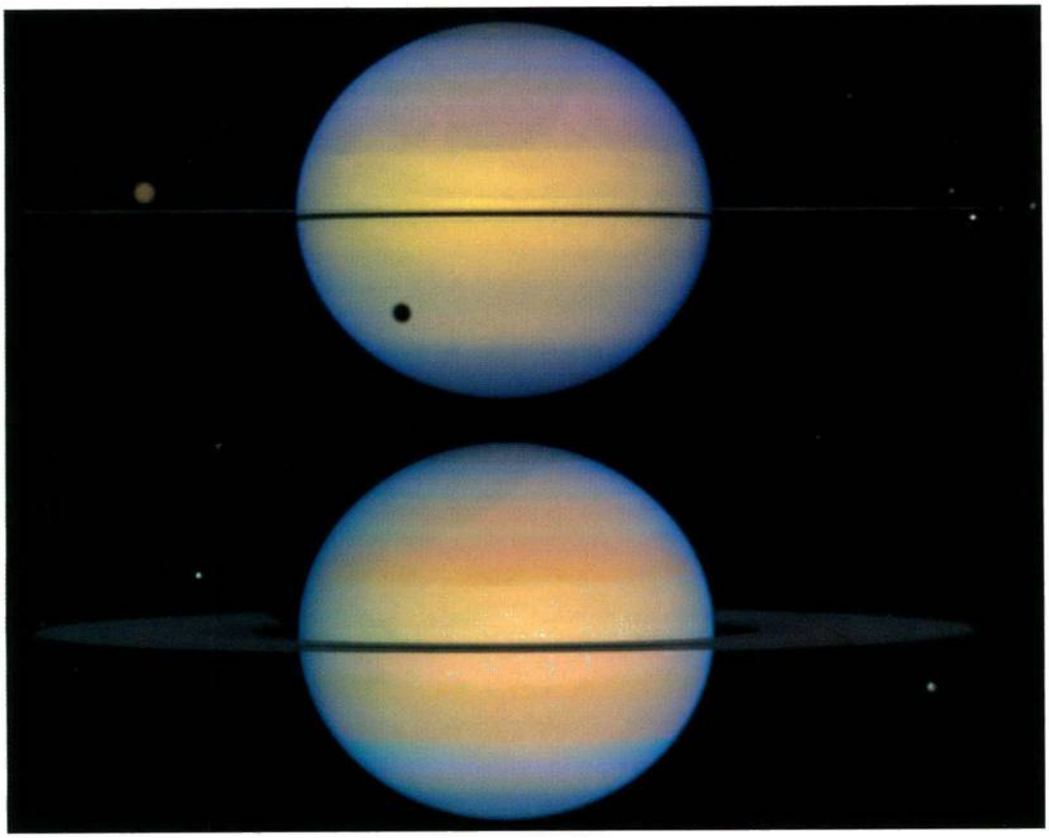
NOW YOU SEE IT . . . The Hubble ▲ Space Telescope captured Mars on June 26, 2001 (left) and September 4, 2001, showing the effects of a global dust storm. Bright and dark features on the planet are visible in sharp amateur telescopes, but when Mars nears perihelion, winds may arise that spread an obscuring blanket of dust. NASA, JAMES BELL (CORNELL UNIV.), MICHAEL WOLFF (SPACE SCIENCES INST.), AND THE HUBBLE HERITAGE TEAM (STSCI/AURA)

FROSTY WHITE ICE CLOUDS and ▶ swirling orange dust reveal Mars as a dynamic planet in this sharpest-ever view obtained with the Hubble Space Telescope. Note the dust storm swirling above the northern polar cap, at top. NASA AND THE HUBBLE HERITAGE TEAM

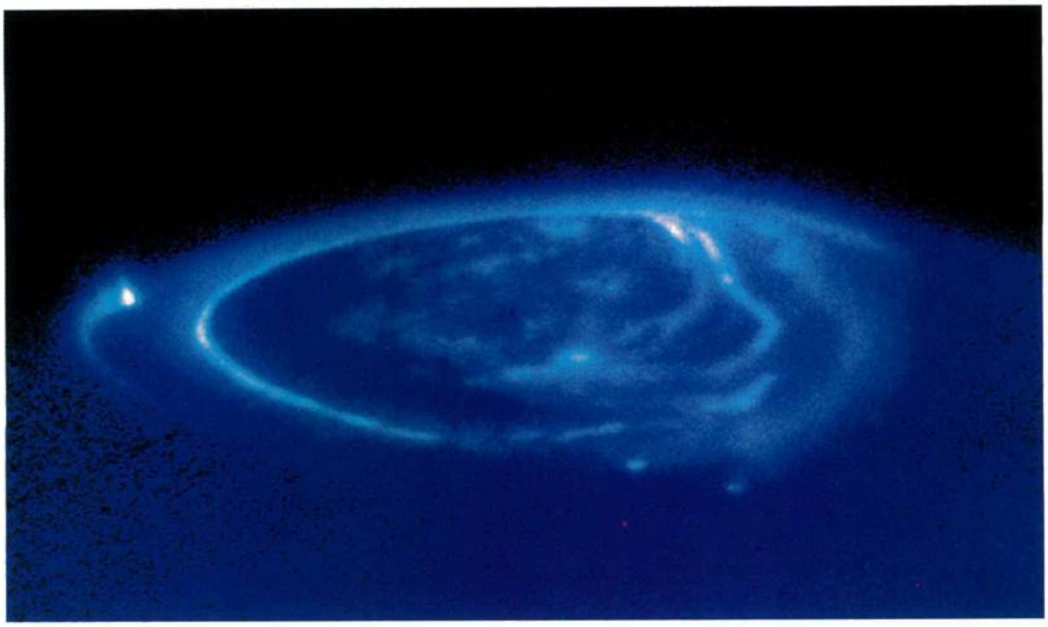
some 10 arcseconds or less across. At times of opposition the diameter of Mars may span more than 20 arcseconds, making details on its surface easier for an observer to see. The greatest opposition, when Mars exceeded 25 arcseconds in diameter, occurred in 2003.

The most obvious martian feature in a telescope is the planet's northern or southern polar cap (depending on which hemisphere the planet presents to us). The polar caps appear as bright white areas covering the poles and are visible in telescopes as small as 2 inches in aperture. The polar caps usually fade when Mars is closest to the Sun. The surface of Mars shows areas that appear dark as well. These markings are regions of low reflectivity. Occasionally areas are visible that are slightly brighter than the surrounding landscape. This occurs when a dust storm is in progress.

Prominent areas on Mars include the Hellas and Argyre Basins, impact features that often appear bright due to shifting dust clouds. A huge canyon called Vallis Marineris exists on the planet, and its 4,500-kilometer length dwarfs Arizona's Grand Canyon. Nearby lies the Tharsis Ridge, which contains several prominent volcanoes including Olympus Mons. Although some observers have reported seeing these volcanoes with backyard telescopes, they are notoriously difficult to spot. Numerous valleys, ridges, and craters dot the martian surface. *Astronomy* magazine regularly provides observing information about Mars, including detailed



SATURN LIVES IN TITAN'S SHADOW (top image) as the Sun stands above the planet's ring plane. The moons huddling around the rings to the right of the image appear white because of their icy surfaces. From left to right they are Mimas, Tethys, Janus, and Enceladus. At bottom, the moon Dione (lower right) slices a long, thin shadow across the whole ring system. ERICH KARKOSCHKA (UNIVERSITY OF ARIZONA LUNAR & PLANETARY LAB) AND NASA

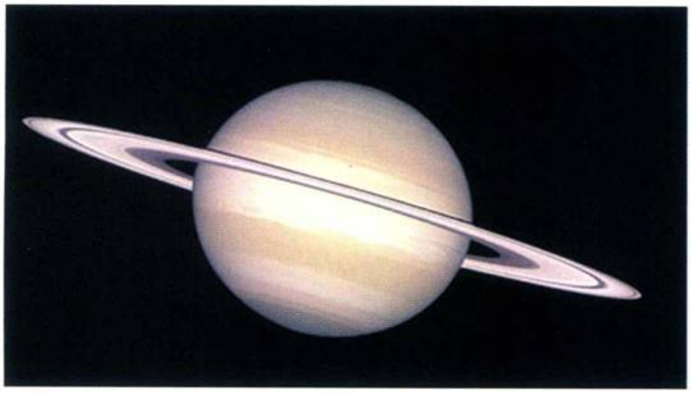


JUPITER'S NORTHERN LIGHTS are caught in this Hubble image taken in ultraviolet light. This gleaming blue luminescent curtain, called an aurora, occurs when high-energy electrons race along the planet's magnetic field into the upper atmosphere. NASA/ESA, JOHN CLARKE (UNIVERSITY OF MICHIGAN)

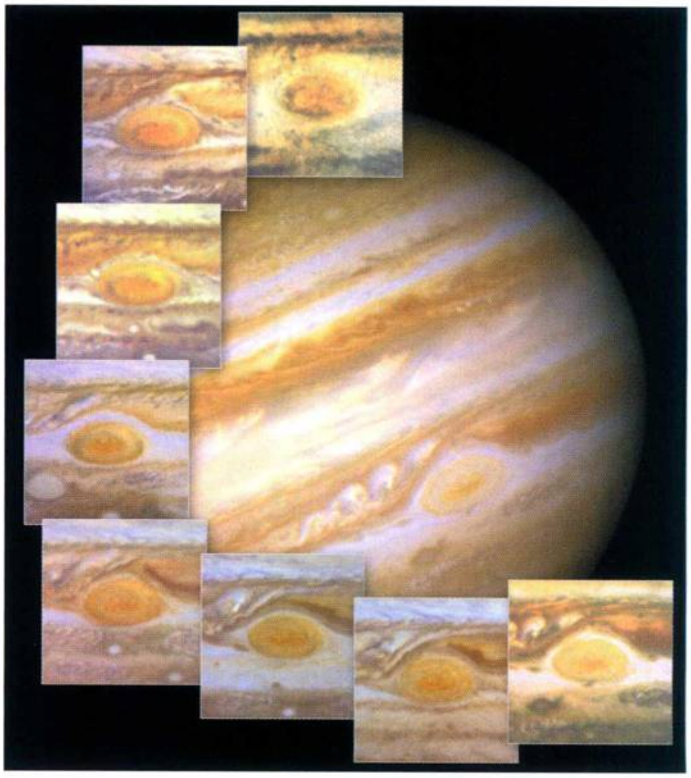
maps and photographs during each Martian opposition.

king of the planets

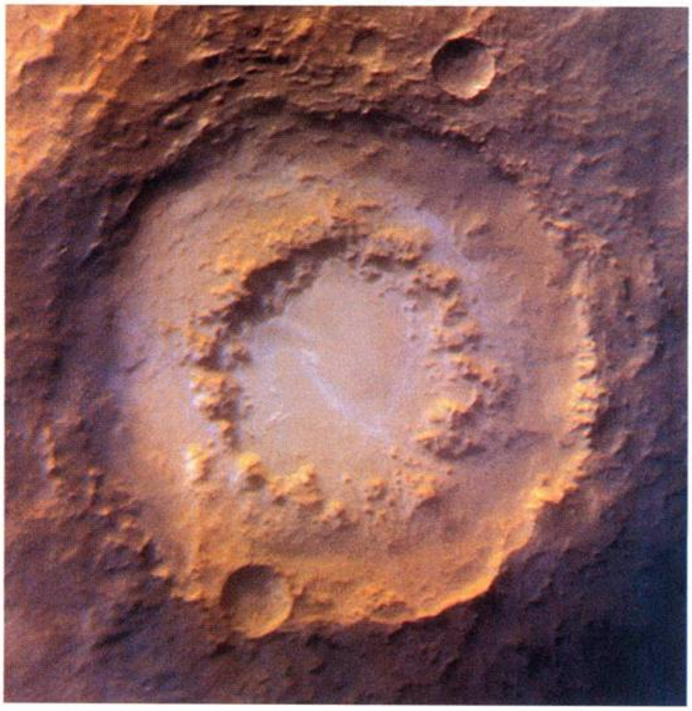
The fifth and largest planet in the solar system, and a dynamic target for a telescope, is Jupiter, which some have labeled a failed star. The prototypical gas giant, Jupiter is an enormous sphere of hydrogen gas. As big as it is, however, it would have to be 80 times as massive to trigger nuclear fusion and become even the smallest star. Had that happened, the rest of our solar system would orbit a double star and the orbital dynamics, temperature, and chemistry of the planets would be markedly different. Life on Earth may not have been possible. Fortunately for us, Jupiter lacked the amount of material — by a longshot — needed to become a star.



SATURN APPEARS CRISP in this ▲ Hubble Heritage Team image. Light bands are zones and dark bands belts; they run parallel to the equator. HUBBLE HERITAGE TEAM



JUPITER'S GREAT RED SPOT has ► fascinated observers since the 17th century. Early explanations suggested the GRS to be a solid island adrift in Jupiter's atmosphere. Rather, the spot is an anticyclonic high-pressure region, much colder than the area surrounding it. The spot is more than 300 years old and twice as wide as Earth. AMY SIMON AND THE HUBBLE HERITAGE TEAM



MARS GLOBAL SURVEYOR ► employed its Mars Orbiter Camera to monitor changes in martian weather and the seasonal activity of polar frost. Lowell is the large crater centered in this image rimmed and filled with frost.

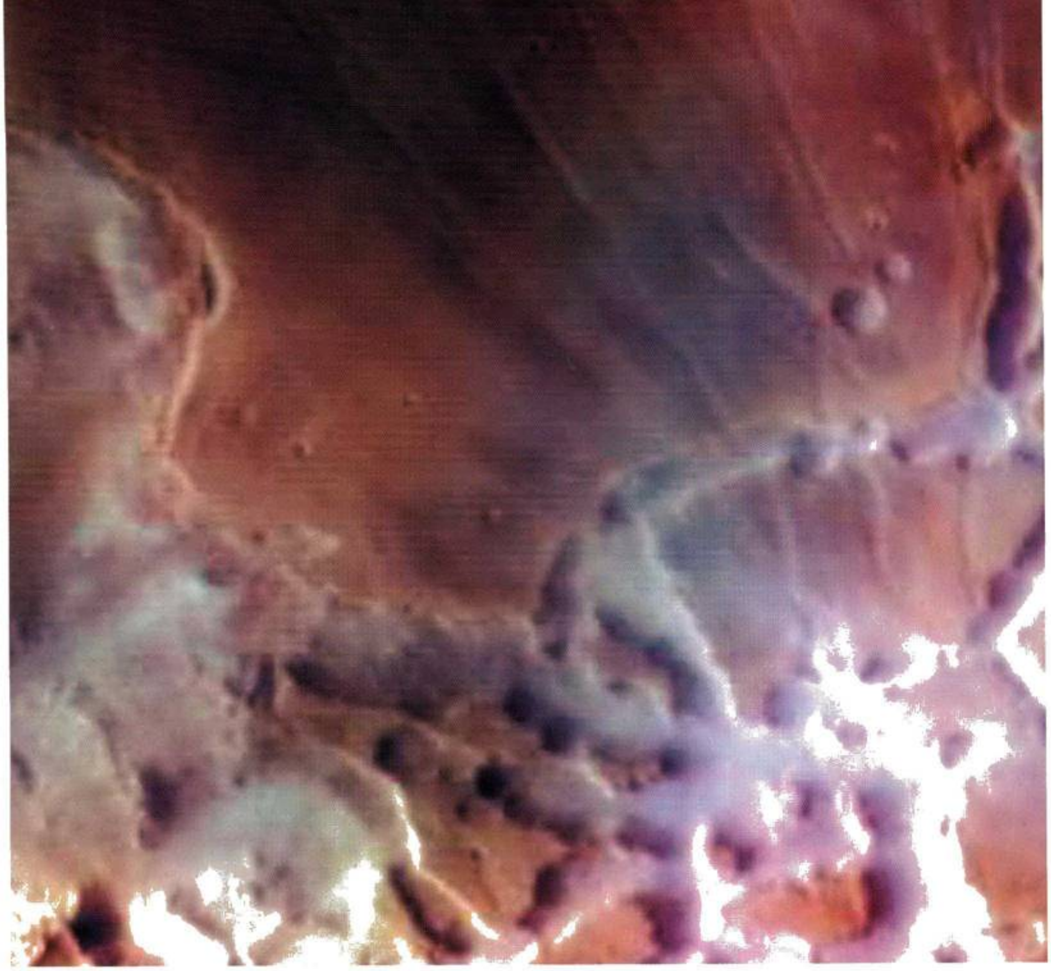
NASA/JPL/MALIN SPACE SCIENCE SYSTEMS

As it exists now, Jupiter measures 142,980 kilometers across at its equator. More than eleven Earths could be stacked end to end across this length. Jupiter is about 1/10 the diameter of the Sun. The king of planets orbits the Sun at an average distance of 5 astronomical units and the jovian "year" is 11.86 Earth years long. Because of its rapid rotation period of less than 10 hours, Jupiter is an oblate spheroid. This means that the planet's shape has been deformed from that of a perfect sphere. Jupiter's polar diameter is a "mere" 133,700 km.

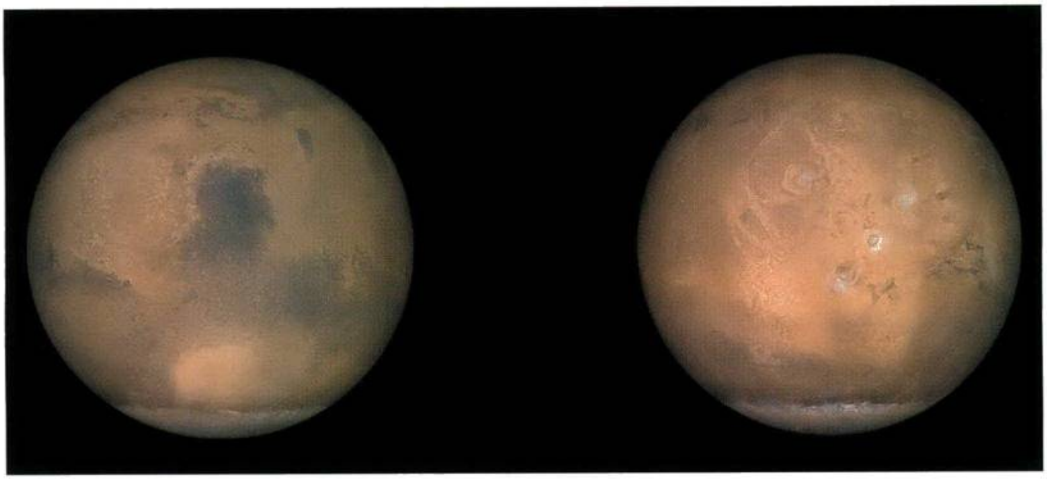
As with the other gas giants, Jupiter is substantially different in composition from the earthlike planets. Jupiter's extremely low density, only 1.3 times that of water, suggests that it is composed almost entirely of hydrogen and helium. Scientific probes released into Jupiter's atmosphere found higher wind speeds, pressures, and temperatures than expected. It has long been known that Jupiter is a heat source — it gives off twice as much infrared radiation as it receives from the Sun.

The jovian "surface" we see in a telescope has many layers of thick clouds in the planet's atmosphere. Some 1,000 kilometers below the upper cloud deck lies a sphere of liquid hydrogen, and some 30,000 kilometers below the clouds lies a core made of metallic hydrogen. A relatively small rocky core some 10 to 20 times the mass of Earth probably exists at Jupiter's center. The planet has no solid surface like those of the terrestrial planets.

Coated by thick layers of clouds and driven by internal heat, rapid rotation, and high pressure, the jovian atmosphere is perhaps the most complex known. Reddish-brown belts and lighter-colored zones cross the planet parallel to the equator. These have gas flows that descend far below. White and yellowish zones are high-altitude cloud decks. Weather systems form and stay within the zones, creating the many bands and belts visible on the planet.



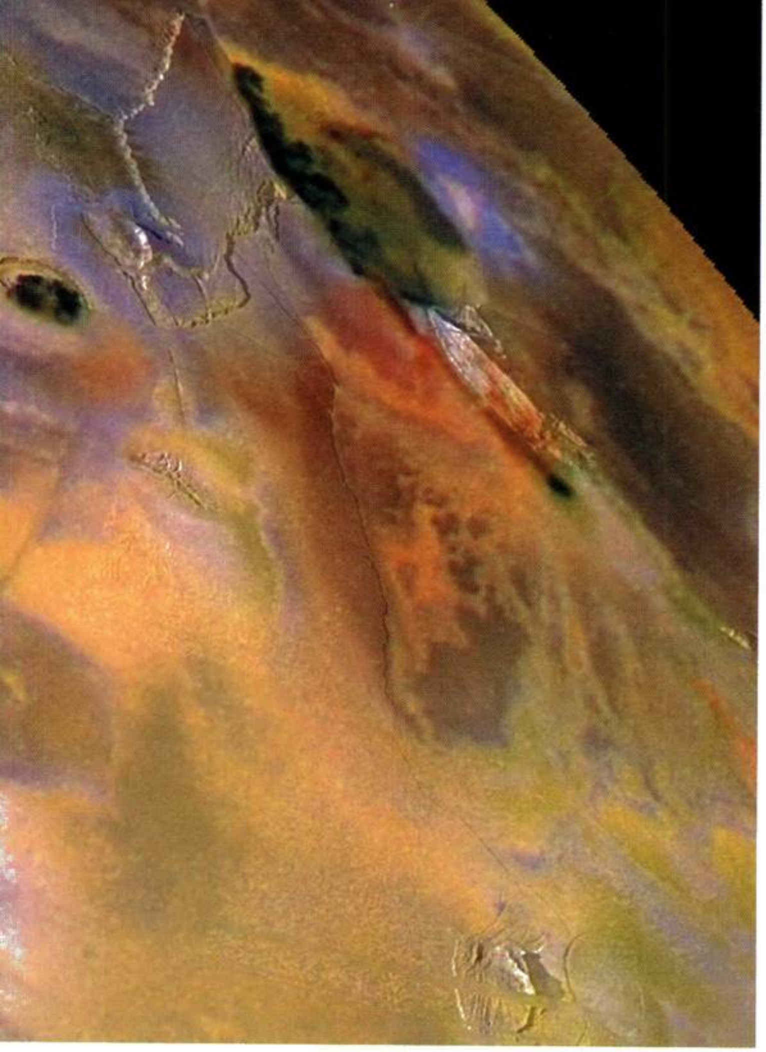
FLUORESCENT BLUES AND GREENS colorfully reveal clouds contrasted against the deep rust-colored martian desert. As the Sun rises over Noctis Labyrinthus, luminescent clouds of water ice formed within the tributary canyons of this high-plateau region of the Red Planet. NASA/JPL/USGS



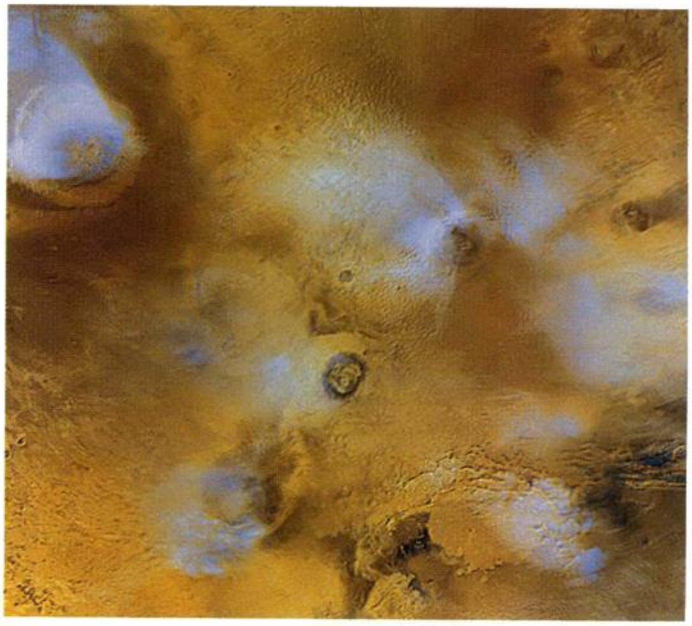
TWO SIDES OF MARS are revealed in Mars Global Surveyor images of the planet — Tharsis (right) and Hellas Basin (left). Water ice crystals shroud the four largest volcanoes in Tharsis during late northern summer. Hellas Basin is Mars's largest impact basin, stretching across 1,370 miles. NASA/JPL/MALIN SPACE SCIENCE SYSTEMS

The equatorial region of Jupiter contains huge cyclonic storms like the Great Red Spot, a storm twice as large as Earth that has been observed for hundreds of years. High clouds contain vast amounts of ammonia while lower clouds consist of sulphur, hydrogen, and phosphorous compounds.

As of this writing, Jupiter has 39 moons that orbit the planet like a solar system in miniature. Of these, four so-called Galilean moons are by far the brightest and are immediately noticeable in backyard telescopes. Discovered by Galileo in 1610, Io, Europa, Ganymede, and Callisto are so large that big amateur telescopes on nights of steady seeing can show these moons not as points of light but as tiny disks. The diameters of these moons are 3,630 kilometers (Io), 3,120 km (Europa), 5,260 km (Ganymede), and 4,800 km (Callisto). The Galilean moons are among the largest moons in the solar system. Ganymede is, in fact, larger than either Mercury or Pluto, and all four of the Galilean moons would be considered planets if they orbited the Sun rather than Jupiter. At an orbital distance of 55,000 km, the jovian system has another feature, a thin, dark set of rings. Discovered by the Voyager 1 spacecraft in 1977, the rings are composed of rocky boulders and represent a moon that broke apart long ago. Because they are so thin, the rings are not visible from Earth.



JUPITER'S MOON IO appears ▲ bruised and battered in this composite shot combining images taken by NASA's Galileo spacecraft in 1999. Planetary scientists are using these images to relate surface materials to underlying geologic structures. NASA/JPL/UNIVERSITY OF ARIZONA



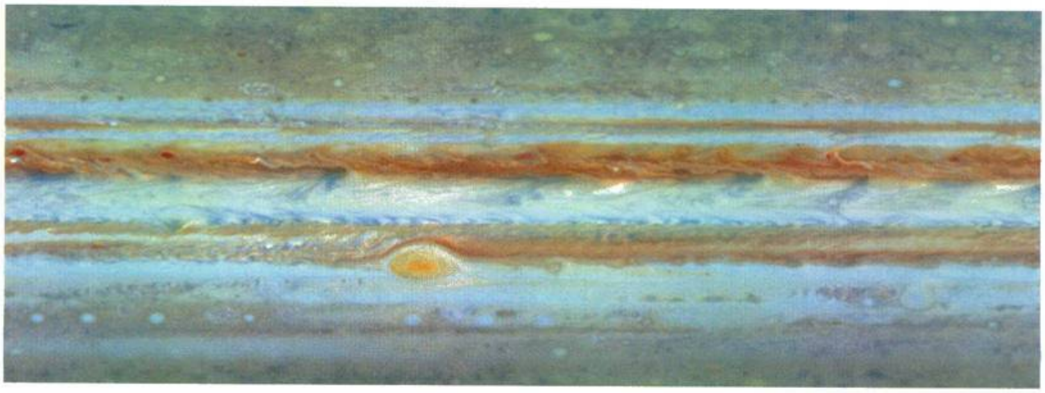
THARSIS REGION VOLCANOES ◀ highlight this color image mosaic obtained by the Mars Orbiter Camera. Gigantic Olympus Mons dominates the upper left corner of the picture. Planetary scientists are monitoring changes in martian weather to plan future observations. NASA/JPL/MALIN SPACE SCIENCE SYSTEMS

In amateur telescopes Jupiter is a delight. The first thing you'll notice are the bands and belts, some appearing darker and in stronger colors than others. If the Great Red Spot is facing Earth you may see it too, appearing like an oval with a pale red or pink color. The planet's overall color is typically described as ocher, but it may appear somewhat yellowish-brown. Also, take note of the four bright Galilean moons. You may see them eclipsed by Jupiter or pass in front of the planet, casting a shadow onto the upper cloud deck, as they slowly revolve about Jupiter's mighty globe.

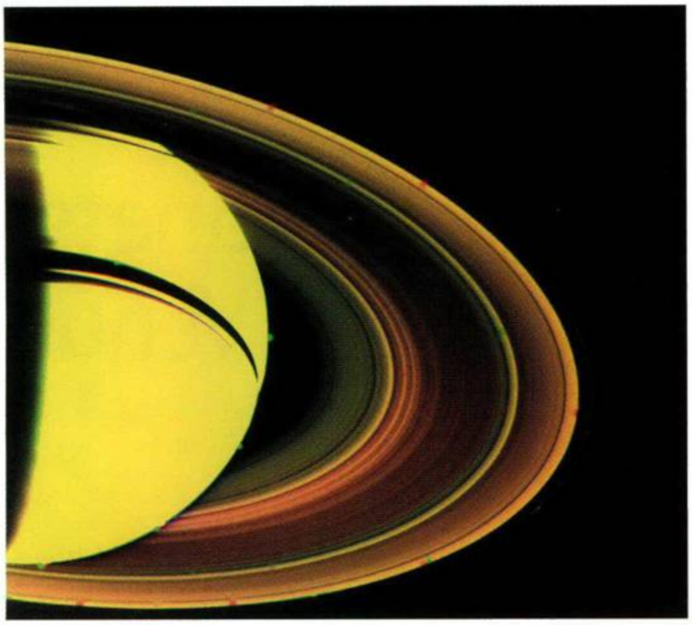
the ringed world

Although it doesn't offer telescopists as much cloudtop detail as Jupiter does, Saturn may be even more inspiring than its fellow gas giant. Saturn and its rings comprise one of the greatest sights in astronomy, one that will stick with you long after you've seen it for the first time. The sixth planet from the Sun, Saturn measures 120,540 kilometers in diameter, over nine times Earth's diameter and $\frac{1}{11}$ the diameter of the Sun. Saturn orbits the Sun at a distance of 9.5 astronomical units and completes one saturnian "year" every 29.46 years. Saturn's famous rings, the planet's most prominent and famous feature, span 600,000 miles across — nearly half the diameter of the Sun.

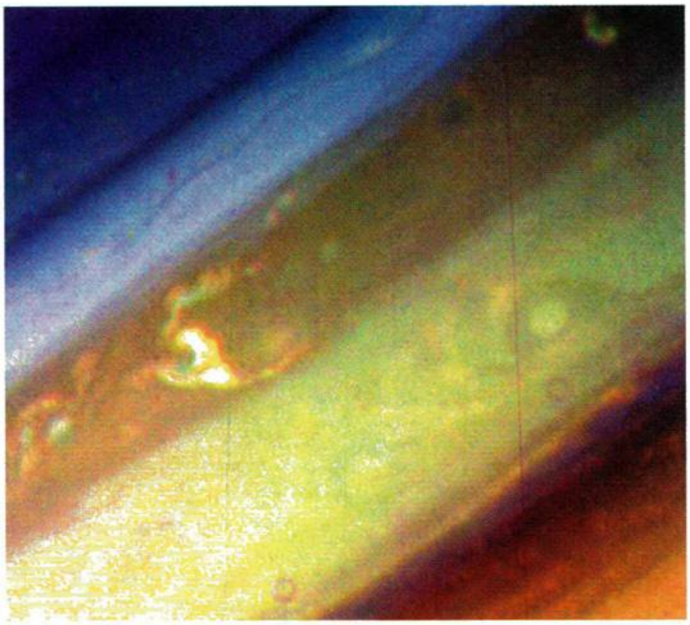
One of the most curious aspects of Saturn is its low density, which is less than that of water. If one were to place Saturn in a giant bathtub filled with water, it would float. Like Jupiter, Saturn is composed chiefly of hydrogen and helium with smaller amounts of methane, ethane, ammonia, and water. Saturn probably consists of an iron-laden rocky core and an outer core of ammonia, methane, and water. This is encased in liquid metallic hydrogen, which in turn lies deep within liquid molecules of hydrogen. Like Jupiter, Saturn has no solid surface, and when we see it in a telescope we're looking at the planet's cloudtops.



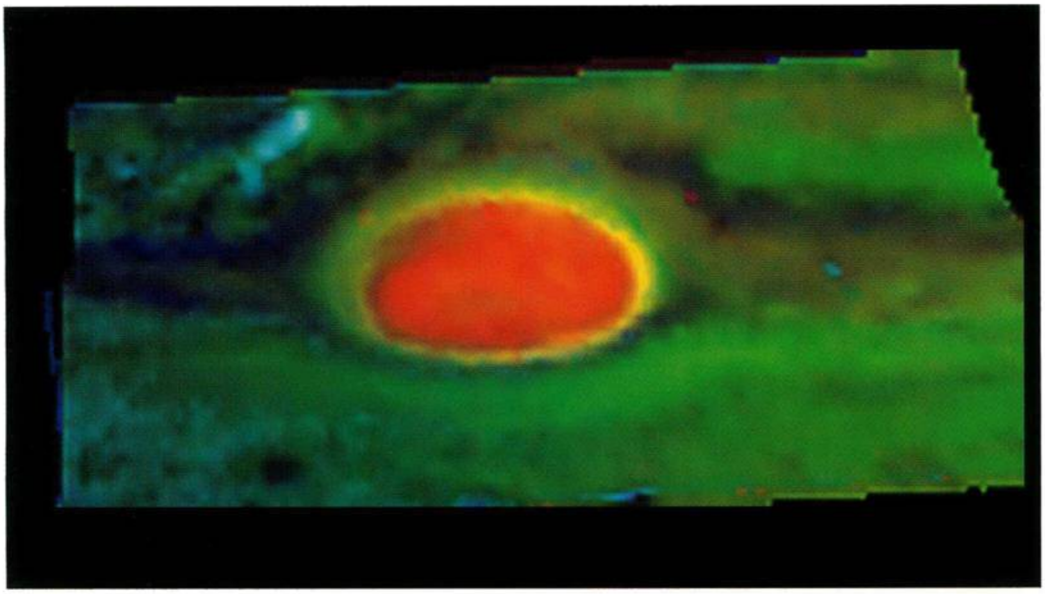
JUPITER UNWOUND. This ▶ widescreen frame from a color movie of Jupiter from NASA's Cassini spacecraft shows what it would look like to unpeel Jupiter's globe and stretch it out onto a wall. NASA/JPL/UNIVERSITY OF ARIZONA



SATURN'S RINGS DOMINATE a ▼ stunning backside image made by the Voyager 2 spacecraft. With a diameter of 967,741 kilometers, the rings consist of thousands of tiny ringlets, each containing numerous individual particles. Less than 3.2 miles thick, the rings practically disappear when edge-on to Earth, which happens about every 15 years. NASA/JPL



SATURN'S CLOUD LAYERS display a variety of cloud features as observed by Voyager 2. Small-scale convective features are visible in the dark belt (center); an isolated cloud with a dark ring is seen in the lighter zone; and a longitudinal wave appears in the brighter zone (right of the center belt). ▲ NASA/JPL



THE FIRST AMMONIA ICE CLOUD ◄ ever observed on Jupiter shows up light blue on this image taken by the Galileo spacecraft. This cloud, seen to the northwest (upper left) of the Great Red Spot, was produced by powerful updrafts of ammonia-laden air from deep within Jupiter's atmosphere. NASA/JPL

Also like Jupiter, Saturn displays a range of weather phenomena in its layers of clouds. Saturn radiates heat from within and this drives storms, belts, and zones of clouds like those on Jupiter. Saturn's atmospheric activity is far more subtle, however, so changes are not as easily observed with earthbound telescopes.

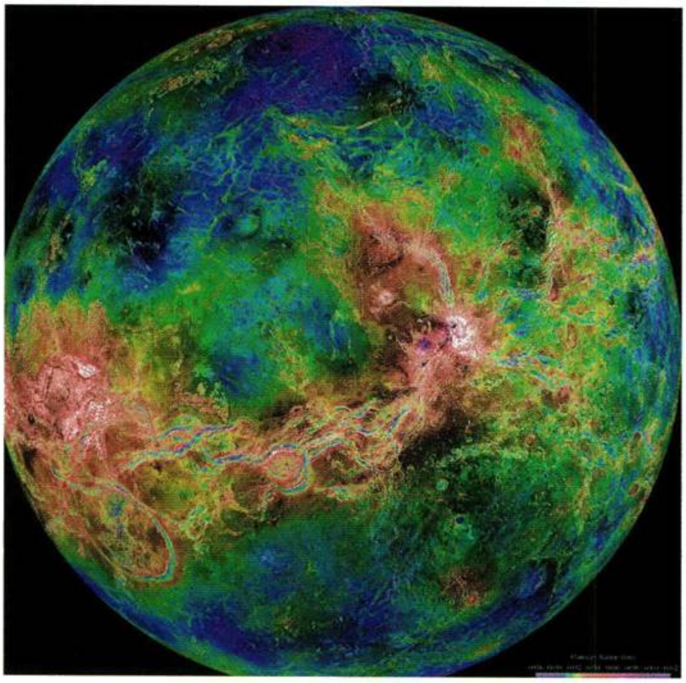
In addition to the rings, Saturn, at the time of this writing, has 30 moons. By far the largest and brightest of these is Titan, which is visible in a telescope as a tiny "star" near the planet on any good night of observing. Titan measures 5,150 kilometers across, making it one of the largest moons in the solar system and larger than either Mercury or Pluto.

When you observe Saturn, take note not only of the rings but also of subtle details on the globe of Saturn itself. Occasionally, white spots and subtle bandings are visible that indicate storms and other weather activity in the cloudtops of the planet.

Saturn, Jupiter, and Mars will give you hours of enjoyment when viewed with your telescope. They are the greatest wonders of the solar system, filled with striking sights and ever-changing detail. Once you get used to watching these planets you may find it hard to devote observing time to galaxies or nebulae!

the inner planets: Mercury and Venus

In a very approximate sense the solar system has three main constituents (not including the Sun): a set of inner, rocky bodies, a group of large gaseous planets, and an outer cloud of planets, miniplanets, and cometary nuclei made up almost entirely of dirty ice. Of the rocky or terrestrial planets close to the Sun, we should really include Mercury, Venus, Earth, and Mars. Because we needn't discuss observing Earth with a telescope, and because we examined Mars in the previous chapter, we'll now focus attention on the two closest planets to the Sun, Mercury and Venus.



A NEON-SPLOTCHED BILLIARD BALL, Venus shows varying terrain in this mosaic created from Magellan satellite data. Blue areas signify lower elevations, while pink represents higher areas. ▲

NASA/JPL/USGS

Although Mercury and Venus are relatively close to Earth, before 1965 astronomers didn't know a great deal about them. The smallest features known on Mercury and Venus were several hundred kilometers across. But the advent of spacecraft missions to the inner planets beginning in 1965 painted a detailed picture of these worlds as intensely hot, inhospitable places with marked contrasts.

the iron planet

Mercury is the closest planet to the Sun. Mercury measures 4,879 kilometers across — under half Earth's diameter — and orbits the Sun at a distance between 0.3 and 0.47 astronomical units. It is less than half as far to the Sun as Earth. Mercury's "year" lasts 88 days. The planet has no moons. Imagery from spacecraft show that Mercury resembles the Moon more than any other solar system body. It is heavily cratered, barren, and without much variety of geological features. If Mercury had an early atmosphere, it was eliminated long ago by impact bombardment and by the Sun's radiation. Mercury is a stark world located in a very inhospitable place.

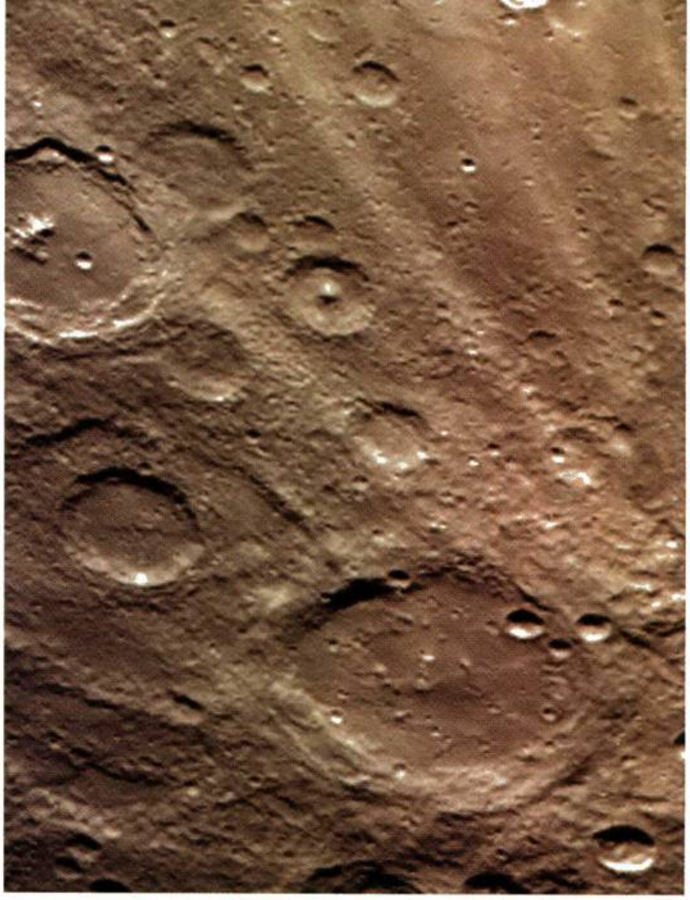
More than any other body in the solar system, Mercury deserves recognition as the iron planet. It consists of a large nickel-iron core (90% iron and 7% nickel) that probably measures 3,600 kilometers across. The planet's mantle and crust, then, are together possibly only 600 kilometers thick.

Much of Mercury's surface resembles the Moon. But Mercury, unlike the Moon, contains large, open plains in its highlands. Because of Mercury's higher gravity, it contains far fewer large craters than does the Moon. On Mercury the gravity constrains the impact debris into a smaller area. Mercury also contains a large number of peculiar cliffs that run along for hundreds of kilometers across its surface. These may have formed as the planet's red-hot iron core cooled and shrank, pulling the planet's "skin" ever tighter. The most notable single feature on the planet is the Caloris Basin, a huge impact crater stretching 1,290 kilometers across. Because Mercury lacks an atmosphere to moderate temperatures, sunlight makes them wildly variable. Afternoon highs usually hit the 425° C mark, while at night the temperature plummets to a bone-chilling –175° C.

viewing Mercury with eye and telescope

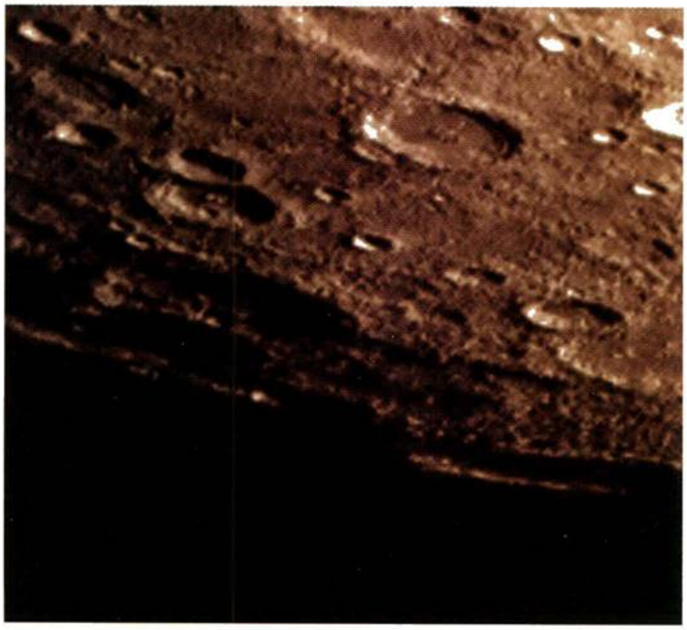
Because Mercury lies so close to the Sun, it never strays far from the Sun in our sky. For this reason, few people have realized that they were looking at Mercury. The planet is relatively bright, typically shining at about magnitude 0, making it easily visible to the

LIKE A GIANT PUZZLE, a mercurian ▶ mosaic appears stark like the Moon, speckled with craters and areas of lava-flooded plains. NASA/JPL

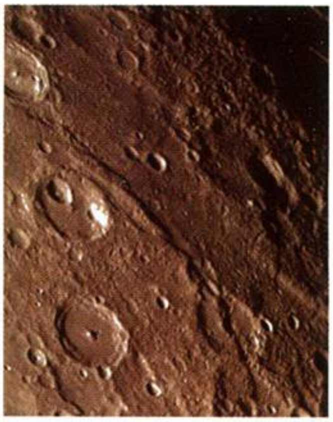


A CHOCOLATE GLOBE reveals moonlike features on Mercury. Smooth plains rather than deep craters dominate this hemisphere. More than 140 frames taken over a span of two hours were pieced together to form this image. NASA/JPL/NORTHWESTERN UNIVERSITY

EJECTA FROM A LARGE CRATER radiates outward on Mercury, visible as light, parallel streaks. Mariner 10 took this image on September 21, 1974. The associated crater lies to the south, outside the frame, near Mercury's South Pole. NASA/JPL/NORTHWESTERN UNIVERSITY



MERCURY'S CRATER-RIDDEN SOUTH POLE lies beyond the large crater at lower center. NASA/JPL/NORTHWESTERN UNIVERSITY



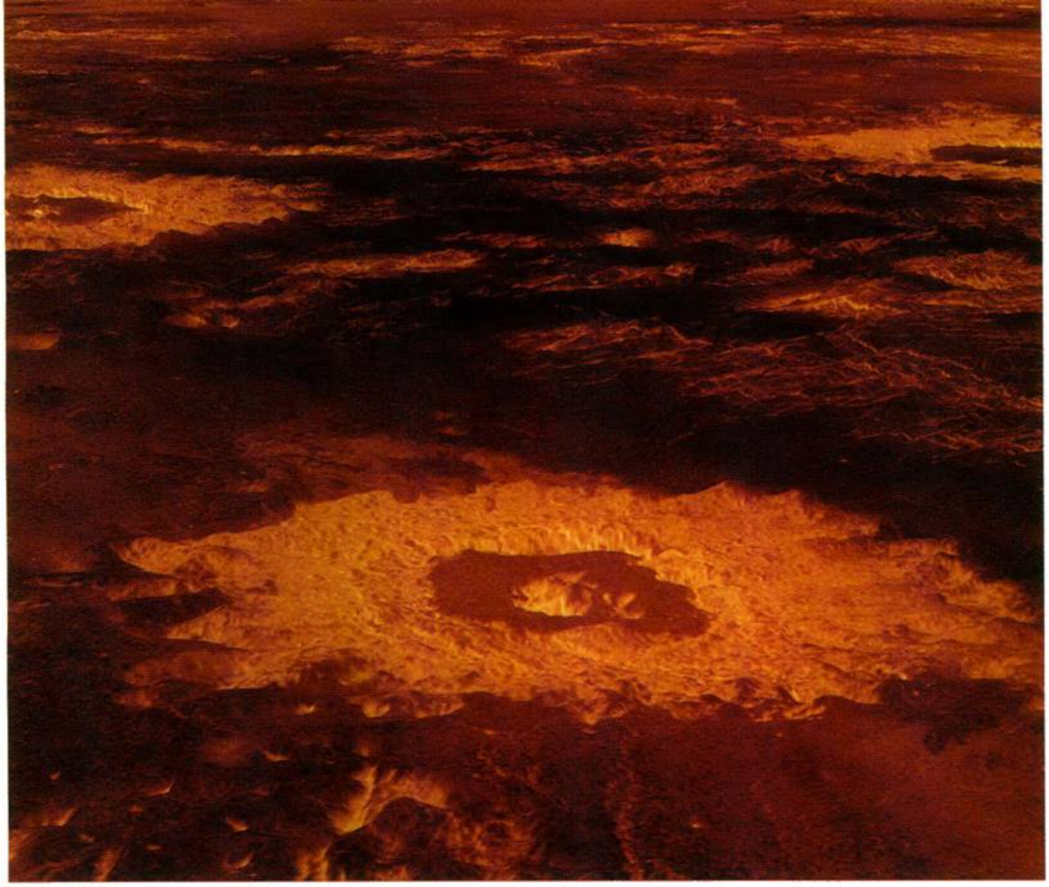
A 300-KILOMETER SCARP extends from the upper left to the lower right of this image of Mercury's surface. Scarps, or cliffs, form as a result of compressive forces due to crustal shortening. NASA/JPL/NORTHWESTERN UNIVERSITY

naked eye. Because it strays only a short distance from the Sun, you'll most often see it while the sky is in twilight after sunset or before sunrise. Binoculars are often handy for initially spotting Mercury's soft glow against a twilight sky.

Telescopically, Mercury is a challenging object. The lack of contrast in a twilight sky and the planet's small diameter (typically between 5 and 10 arcseconds) makes seeing any detail on Mercury's surface extremely difficult. Yet experienced planetary observers using long-focal-length telescopes occasionally report shadings and areas of subtle bright patches on the planet's disk. Because of the orbital geometry of Sun, Mercury, and Earth, we see Mercury go through phases as it and we orbit the Sun. The chief observational challenge with Mercury is to see these phase changes, and you may wish to sketch or photograph the planet in a variety of phases.

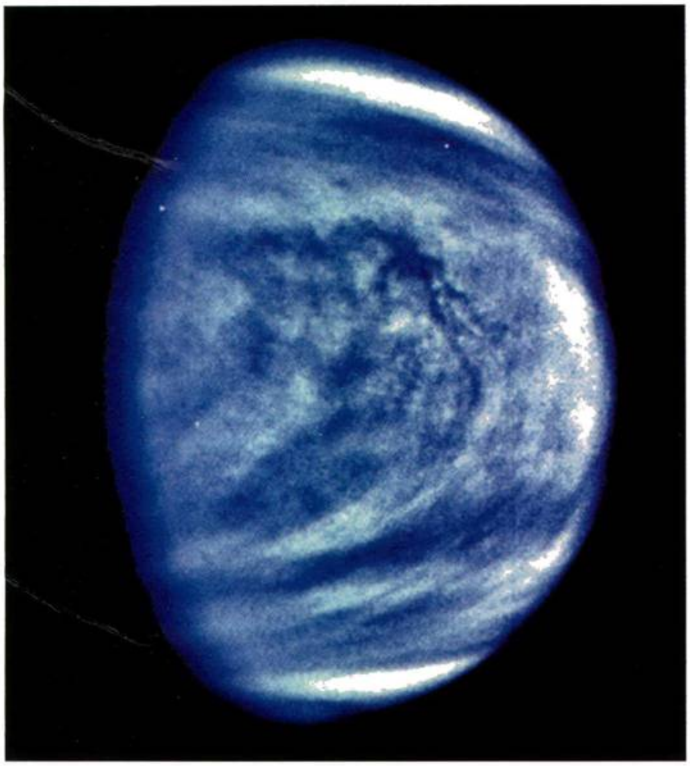
planet of fire

Second in closeness to the Sun, Venus is a substantially different place than its neighbor Mercury. Venus has a thick, dense atmosphere composed mostly of carbon dioxide. Early thoughts that Venus — similar in size to and not too far from Earth — was Earth's "sister planet" collapsed as spacecraft analyzed Venus over the past two



BAKING IN LAVALIKE HEAT, Venus's surface shows three impact craters in a 3-D perspective view. The predominant feature in this image is Howe Crater, at bottom center, which spans 37 km (23 mi). While it appears larger, it is actually smaller than the two craters in the distance. NASA/JPL

MINUSCULE IN COMPARISON, Mercury's tiny black disk silhouettes the northern edge of the Sun in this 1/60-second exposure. Chris Cook used Kodak Ektachrome E200 film and an off-axis 3.8D Baader AstroSolar filter to capture the image. CHRIS COOK

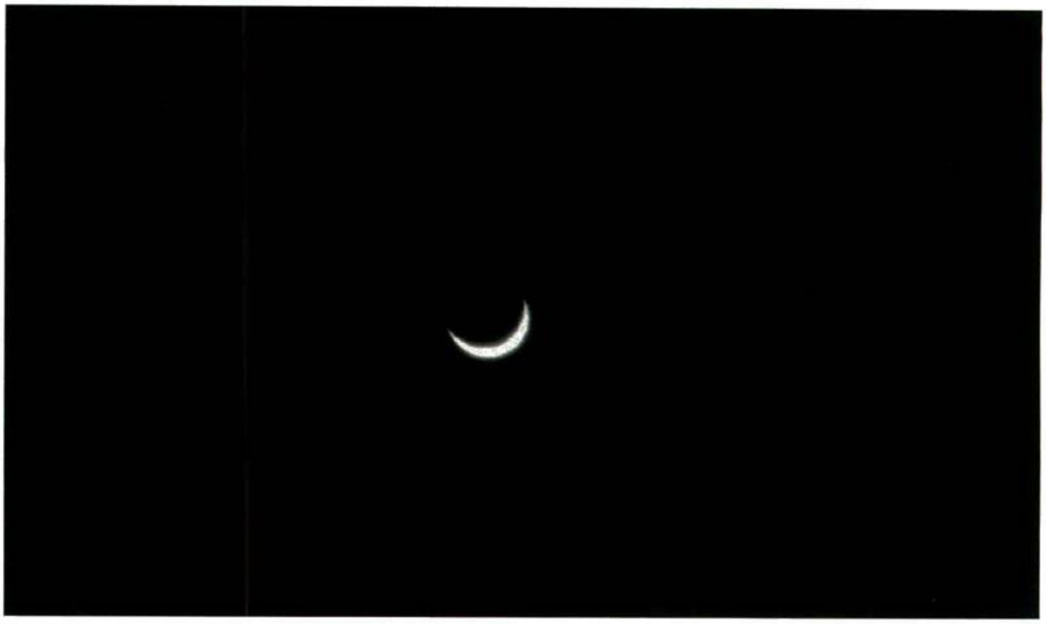


VENUS'S BLUISH HUE in this image results from a violet filter on Galileo spacecraft's Solid State Imaging System. The bluish tint helps to emphasize subtle contrasts in the planet's cloud markings. NASA/JPL

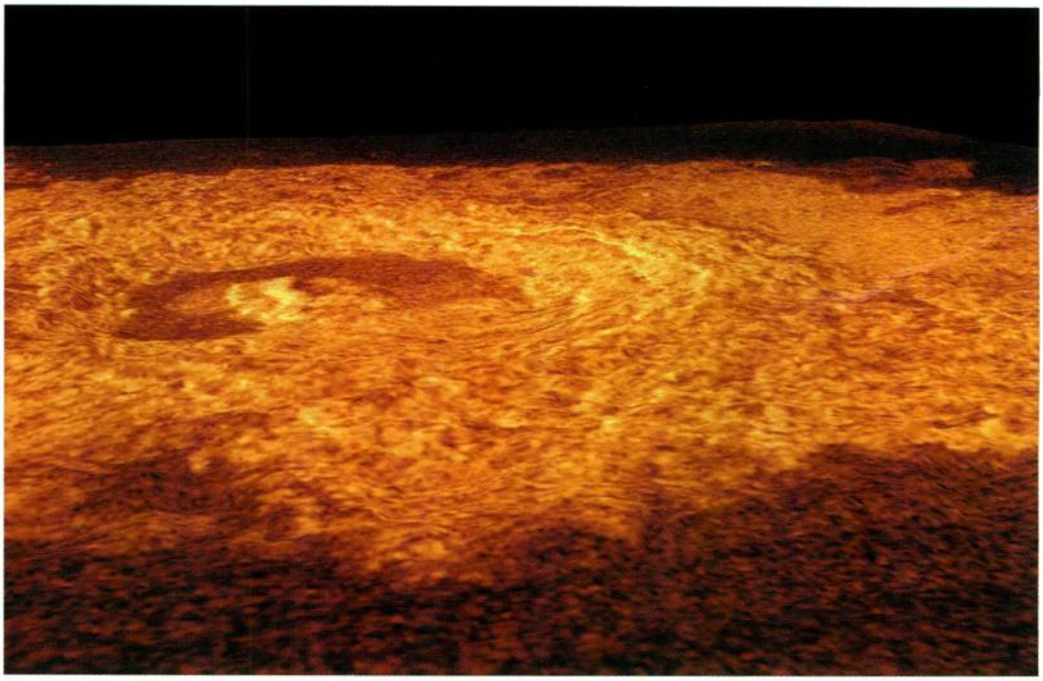
decades. Instead of a world similar in many ways to Earth, astronomers found the most hellish place in the solar system.

Venus measures 12,104 kilometers across, 95% of Earth's diameter. Its density is lower than Earth's and so Venus's mass is smaller than ours as well. Venus orbits the Sun at an average distance of 0.7 astronomical units. The venusian "year" lasts 225 days.

Strangely, the internal composition of Venus may be quite similar to that of Earth's. However, in two critical places — surface and atmosphere — Venus is radically different. The prototypical example of the Greenhouse effect is at work on Venus. Not only is the planet close enough to the Sun to be bombarded by an intense stream of radiation and heat, but the planet's thick atmosphere also acts as a blanket that traps the heat, further raising the temperature and making possible complex



VENUS SMILES for astrophotographer Chris Cook in this March 17, 2001, image. Our sister planet was on the inside curve of its orbital track and consequently was closer and bigger than normal in proximity to Earth. CHRIS COOK

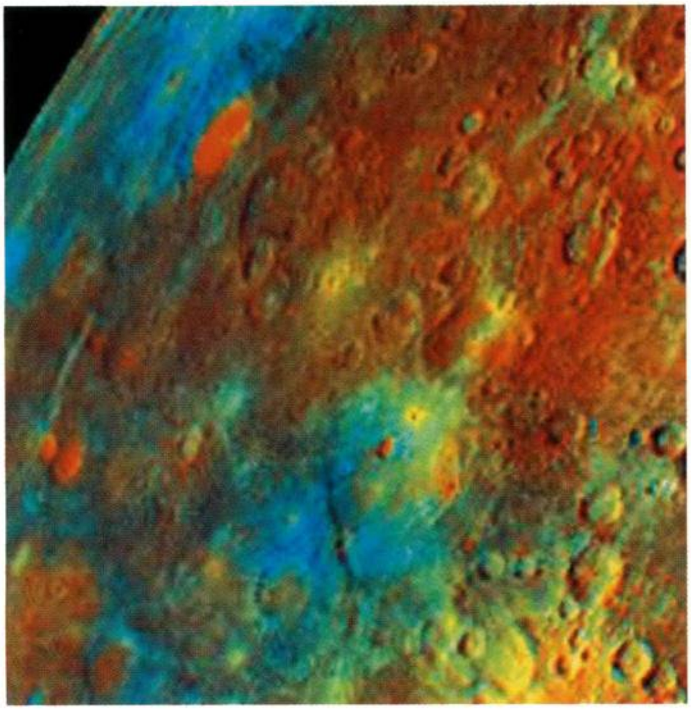


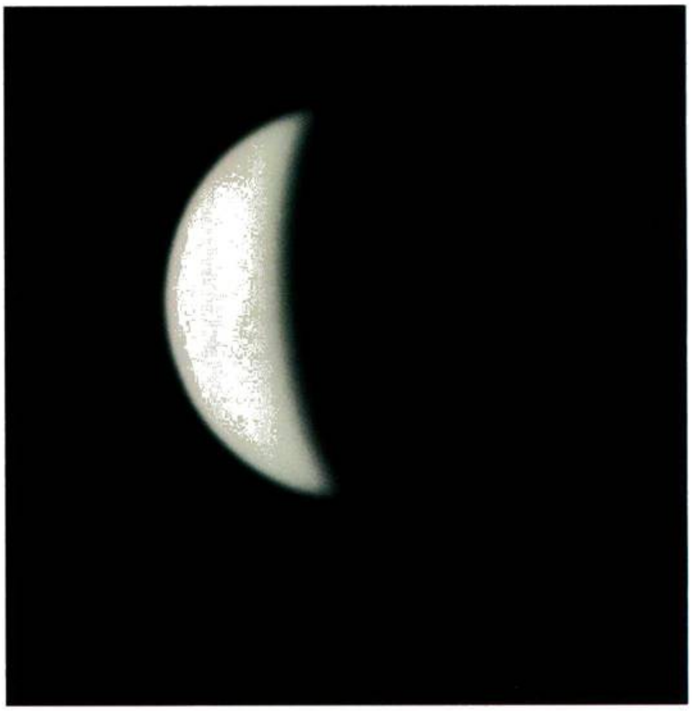
NAMED FOR MARGARETTA RILEY, a 19th century botanist, Venus's Crater Riley stands out in a Magellan radar mosaic. This view was prepared from two left-looking Magellan radar images acquired with different incidence angles. NASA/JPL

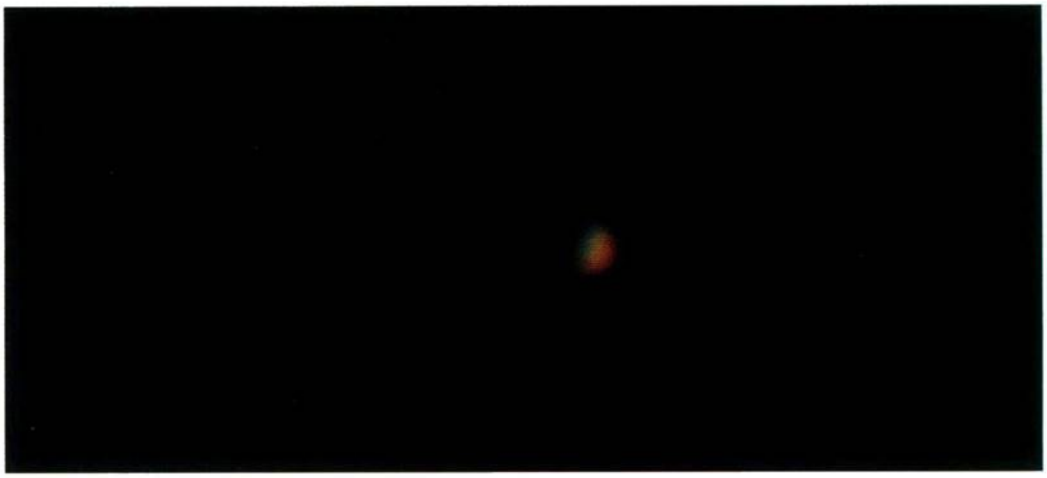
chemistry high in the venusian clouds, chemistry that among other things produces voluminous amounts of toxic gases like sulfur dioxide.

As if that weren't off-putting enough for living beings, the temperatures on Venus are extreme. The average temperature at the top of the 250-kilometer high atmosphere is –45° C, and the temperature on the surface is an astounding 500° C, making Venus — not Mercury — the hottest planet. To make matters worse, Venus's surface pressure is a crushing 90 times that of Earth's. It would be very difficult to visit the surface of Venus, let alone inhabit it. Again, we see evidence of how lucky we are to live on Earth!

Unlike Mercury, Venus displays a fabulous range of geological structures. Large rolling plains blanket about 70 percent of the planet's surface, lowlands cover some 20 percent, and highlands occupy 10 percent of the topography. Many craters have been identified, the result of impacts that occurred before Venus's atmosphere developed to its present density. Two immense areas of volcanic activity exist on Venus, Ishtar Terra and Aphrodite Terra. The highest mountain on Venus is Maxwell Montes, which rises 11.6 kilometers above the planet's surface. Interestingly, of the 1,761







EARTH'S SISTER VENUS shows a ▲ constantly-changing array of phases, visible easily whenever the planet separates itself from the Sun. Jean Dragesco recorded this image with a 14-inch SCT at f/60, Tech Pan 2415 film, and a ¼-second exposure on December 1, 1981. JEAN DRAGESCO

REMOTE MERCURY is small and ◄ never far from the Sun, so recording it as anything more than a "star" is challenging. Amateur astronomer J. T. Howell imaged the planet in 1994 using an 8-inch SCT and Fuji 400 film. J. T. HOWELL

LOOKING MORE LIKE A MOLDY ▼ **PIZZA,** this color composite image of Mercury was created to accentuate the differences among minerals. NASA/JPL/NORTHWESTERN UNIVERSITY

named features on Venus, Maxwell Montes is the only one not named after a female.

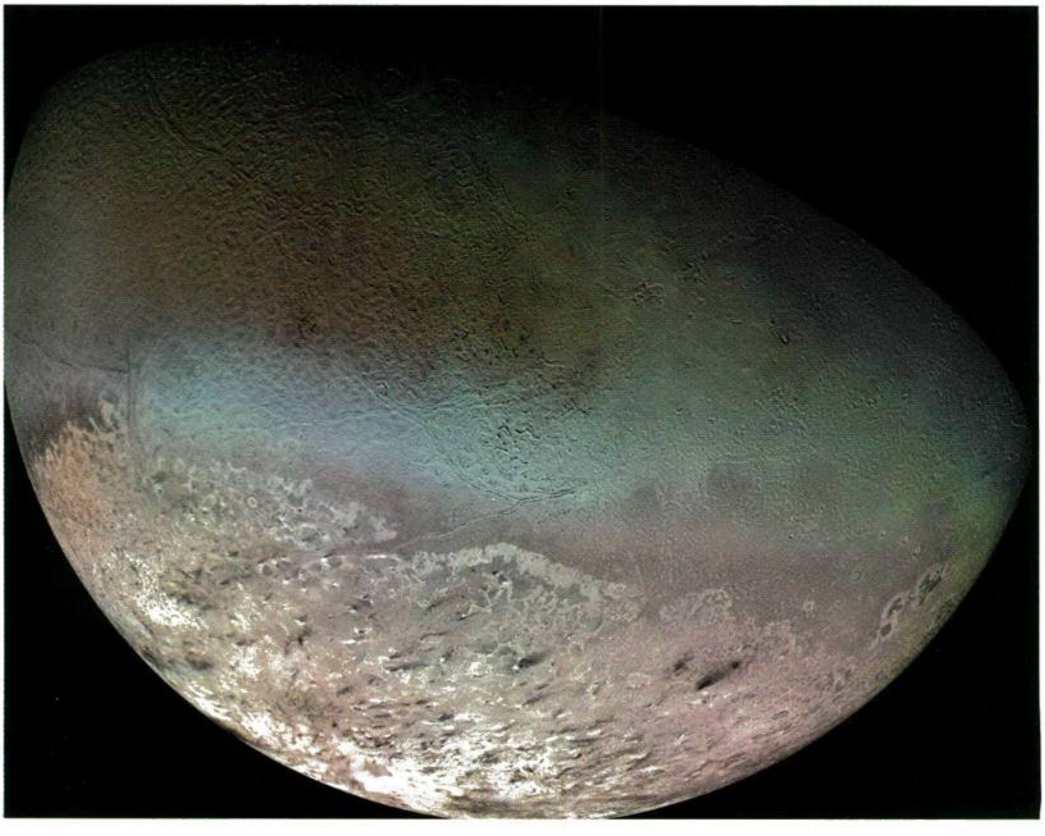
the changing phases of Venus

Like Mercury, Venus never strays far from the Sun in our sky. It is far brighter than Mercury, however — in fact, Venus is the brightest object in the sky after the Sun and Moon — and therefore it is easily recognized as the "evening star" or "morning star" at the transition time of twilight. At a peak magnitude of –4.4, Venus is so bright that it often confuses experienced scientists, or pilots, or other professionals, suggesting the appearance of a "UFO." Venus's brilliance comes from the combination of its closeness to Earth and because its opaque clouds reflect sunlight extremely efficiently.

Like Mercury, Venus displays phases. Although Venus appears substantially larger in the sky than Mercury — up to 64 arcseconds across — the venusian clouds make spotting details on the planet virtually impossible. As with Mercury, skilled planetary observers sometimes report seeing subtle shadings and differences in brightness on the planet's disk. But as with Mercury the challenge here comes in viewing Venus over a great range of phases, from Full, when the planet appears small, to a slender crescent, when it is large.

Although these two worlds of the inner solar system do not offer bands, rings, belts, or other surface details like the spectacular planets Mars, Jupiter, and Saturn, Mercury and Venus are well worth observing. They are morning and evening friends whose calm, steady appearance in the telescope hides a barren, stark world on Mercury and a world of terror on its neighbor Venus.

the outer planets: Uranus, Neptune, and Pluto



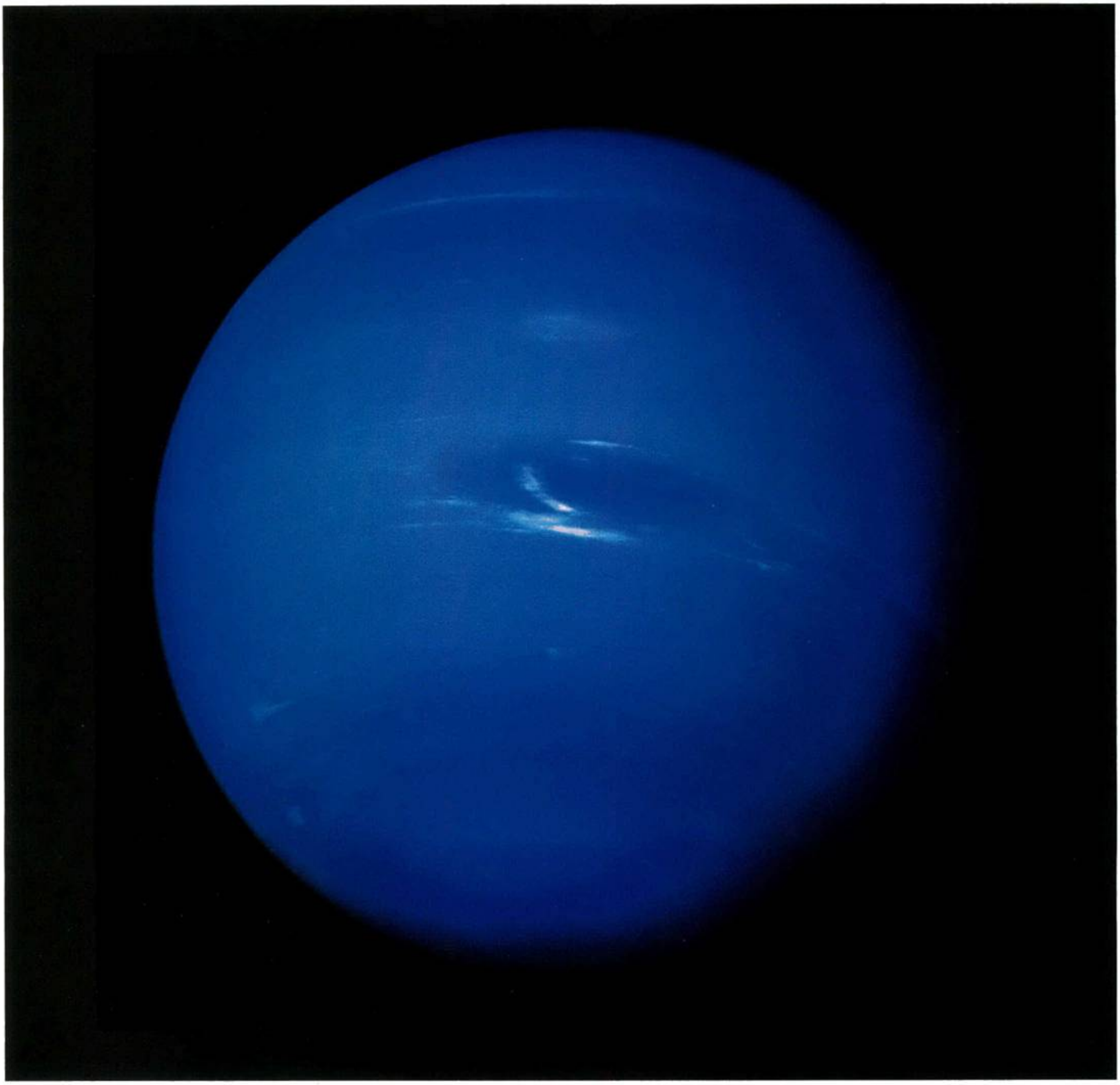
A GLOBAL MOSAIC OF TRITON was taken in 1989 by Voyager 2 during its flyby of the Neptune system. Triton is one of only three solar system objects with a nitrogen-dominated atmosphere and is the only moon with a nitrogen-ice surface. NASA/JPL/USGS

In the middle of the eighteenth century, human knowledge of the solar system seemed pretty complete. Six planets inhabited the solar system, slowly orbiting the powerful central Sun. Then a German-born, English amateur astronomer named William Herschel discovered a seventh planet and in one night turned orderly knowledge into chaos. The planet Herschel discovered was Uranus, and it lay more than twice as far from the Sun as Saturn, the previous outermost planet. The branch of astronomy called "outer solar system research" was born, and it continues today. In 1992, astronomers discovered a 200-kilometer-sized object more distant than Pluto. Provisionally designated 1992 QB_1, the object represents a new class of distant solar system bodies called Kuiper Belt Objects (KBOs).

Starting with 1992 QB_1, astronomers became aware of a vast population of small bodies orbiting the Sun in a region beyond Neptune. There are at least 70,000 of these bodies with diameters larger than 100 km. They begin to be seen near Neptune (30 AU) and end at a distance of about 50 AU. Observations show that these objects occupy a ring or belt surrounding the Sun. This ring is generally referred to as the Kuiper Belt.

In 1781, the solar system doubled in size. In 1846, J. G. Galle at the Berlin Observatory discovered the eighth planet, Neptune. His discovery was a triumph of the branch of astronomy known as celestial mechanics and of Isaac Newton's theory of gravity in particular. Two astronomers, Jean Joseph Leverrier of France, and John Couch Adams of England, using Newton's theory, accurately predicted the position where Neptune could be found. Both had calculated the position of (what would come to be known as) Neptune from observed irregularities in the orbit of Uranus, although it was Leverrier who advised Galle to search for it. This planet, astronomers found, is half again as far out as Uranus. And in the ongoing search to find even more distant planets, Clyde Tombaugh, working at Lowell Observatory in Arizona, found the ninth planet, Pluto in 1930.

The discoveries of Neptune and Pluto relied on complex mathematical calculations and predictions of where such planets might be found. Typically, Uranus

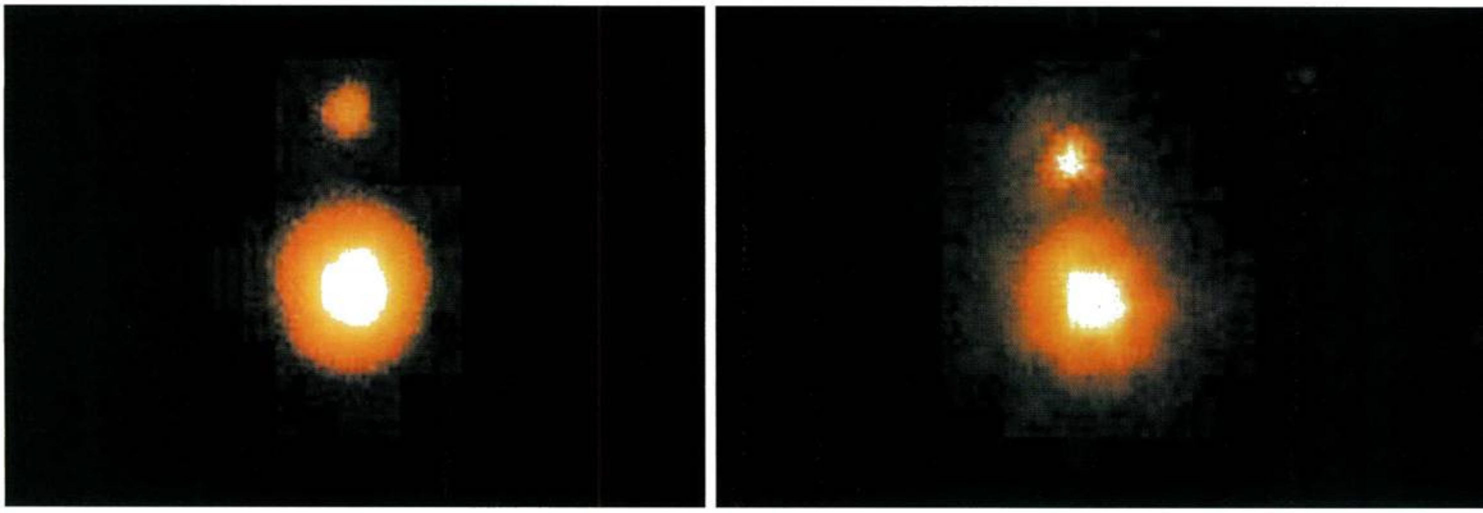


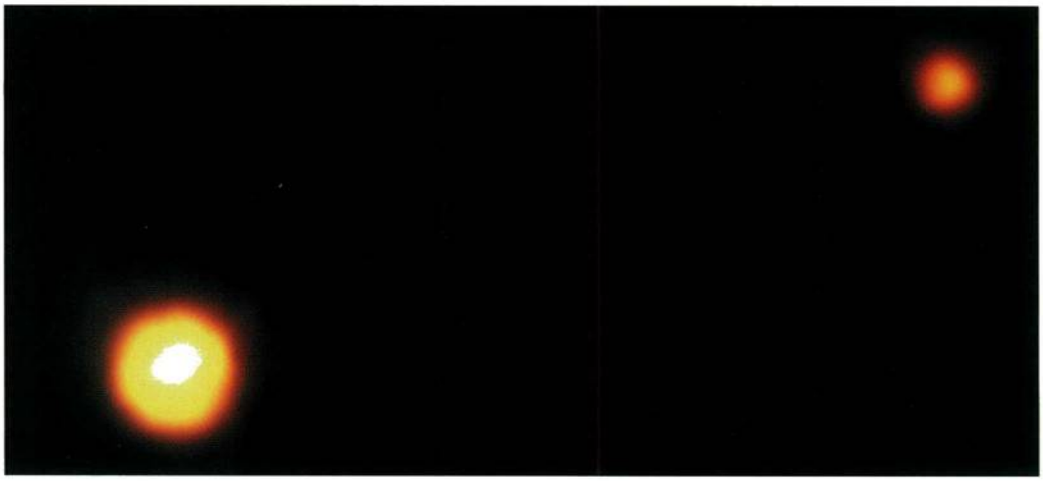
NEPTUNE'S GREAT DARK SPOT, emphasized by bright smudges, stands out in this Voyager 2 image. The fast-moving cloud feature called Scooter lies at bottom left. NASA/JPL

glows slightly brighter than magnitude 6, making it just visible to the naked eye on a superbly dark night. Yet the multitude of 6th-magnitude objects hid the planet from discovery until 1781. Neptune glows at 8th magnitude, making it visible in binoculars but invisible to the naked eye. Pluto is extremely faint at magnitude 14, making it barely visible in a good 8-inch telescope.

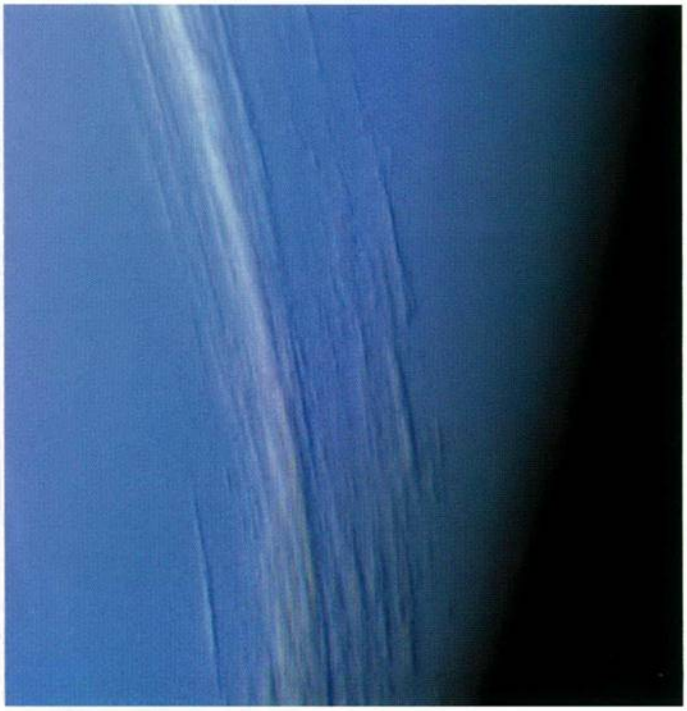
Herschel's world

The discovery of Uranus revolutionized astronomers' idea of the solar system, if for nothing else because it demonstrated the immense size of the Sun's family of planets. Uranus lies at an average distance from the Sun of 19 astronomical units — nearly four times more distant than Jupiter and twice as far as Saturn. Like Jupiter and Saturn, Uranus is a gas giant planet, being composed primarily of hydrogen in a giant sphere. The diameter of Uranus is 51,120 kilometers, more than four times the diameter of Earth. Uranus has a "year," one uranian orbit about the Sun, that lasts 84 Earth years. Curiously, Uranus is tilted 98° with respect to its orbital plane, meaning that at various times during its orbit it displays its poles — not its equator — toward





THE CLEAREST VIEW OF PLUTO ▲ EVER, also showing its moon Charon, was captured with the Hubble Space Telescope on February 21, 1994. At the time, Pluto was 2.6 billion miles from Earth. Pluto and Charon are too close to separate with most instruments. R. ALBRECHT, ESA/ESO SPACE TELESCOPE EUROPEAN COORDINATING FACILITY; NASA



A HIGH-RESOLUTION VOYAGER 2 ▶ IMAGE, shot two hours before the spacecraft's closest approach to Neptune, reveals vertical relief in the planet's bright cloud streaks. Like the other gas giants, Neptune radiates more energy than it receives from the Sun. NASA/JPL

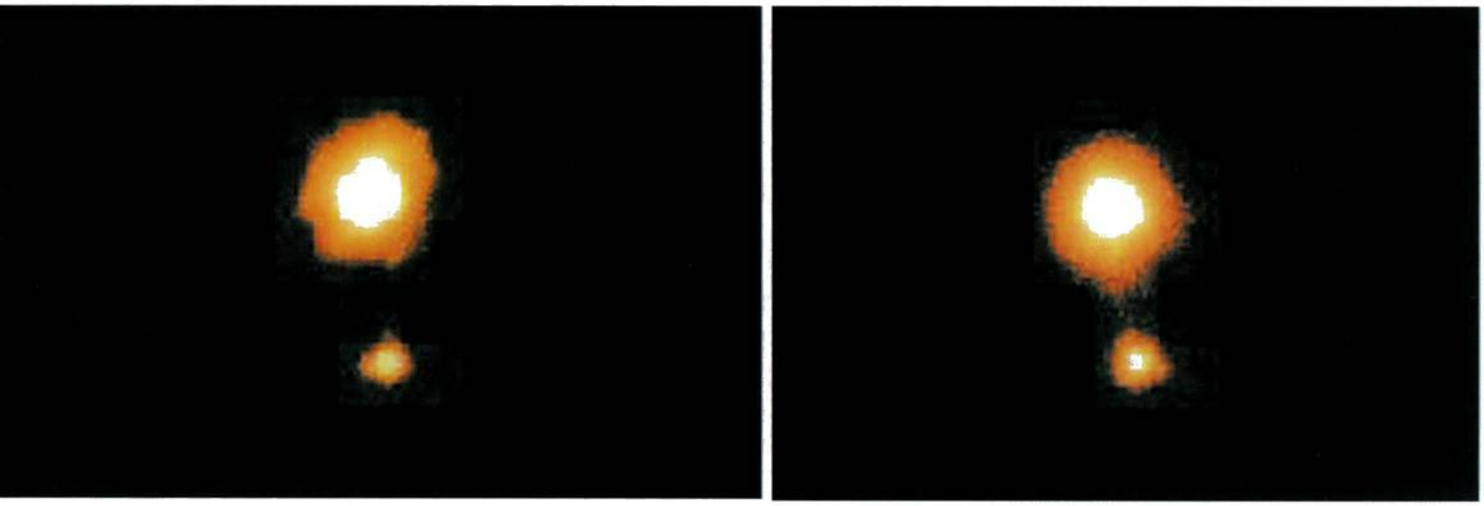
the Sun. It is a planet that has been "knocked on its side."

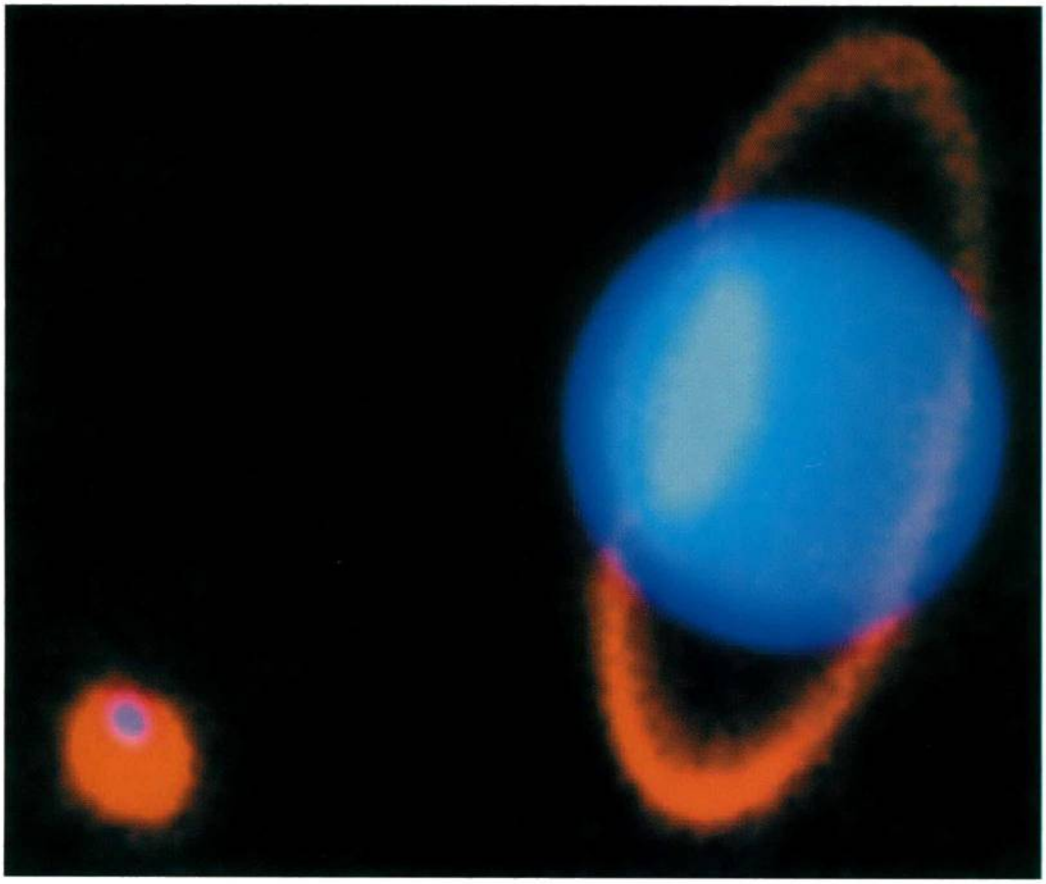
Uranus has a rocky core that is 16,000 kilometers in diameter surrounded by an 8,000-kilometer thick ice mantle. Surrounding this is the part we see: a layer of molecular hydrogen enveloped by a thick atmosphere of hydrogen clouds. This is pretty typical of a gas giant. Uranus also has a thin set of rings and 22 moons as of this writing. Of these, Miranda is the most fascinating. It displays so many different types of planetary surfaces in a single, small moon that astronomers believe it is the result of collisions of large bodies and subsequent activity by impact and flowing surface material.

In a telescope, Uranus appears as an unimpressive, greenish disk about 3.5 arcseconds across. It can easily be seen even in a finder scope. At low power you may recognize it best by the color, and you may have to switch to a moderate magnification to see the planet's disk. Although cloudtop details are not visible in small telescopes, observing Uranus presents a special thrill simply because it is so enormously distant.

surprising, dynamic Neptune

Neptune, the nineteenth century's contribution to new planets, is on a gross scale quite similar to Uranus. It is a large, bluish gas giant with a predominantly hydrogen composition. The planet spans

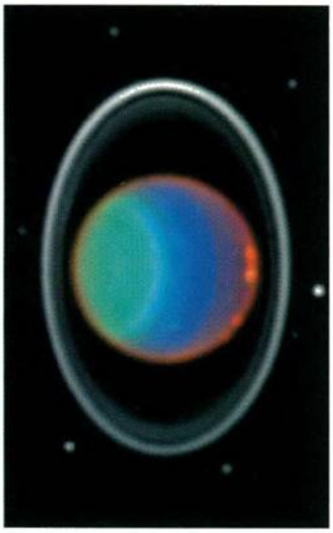




PLUTO AND CHARON'S CLOSE RELATIONSHIP is exposed here by Gemini North and the University of Hawaii's infrared camera dubbed QUIRC. At maximum separation the two are only 0.9 arcsecond apart as seen from Earth. GEMINI OBSERVATORY, NATIONAL SCIENCE FOUNDATION ▲

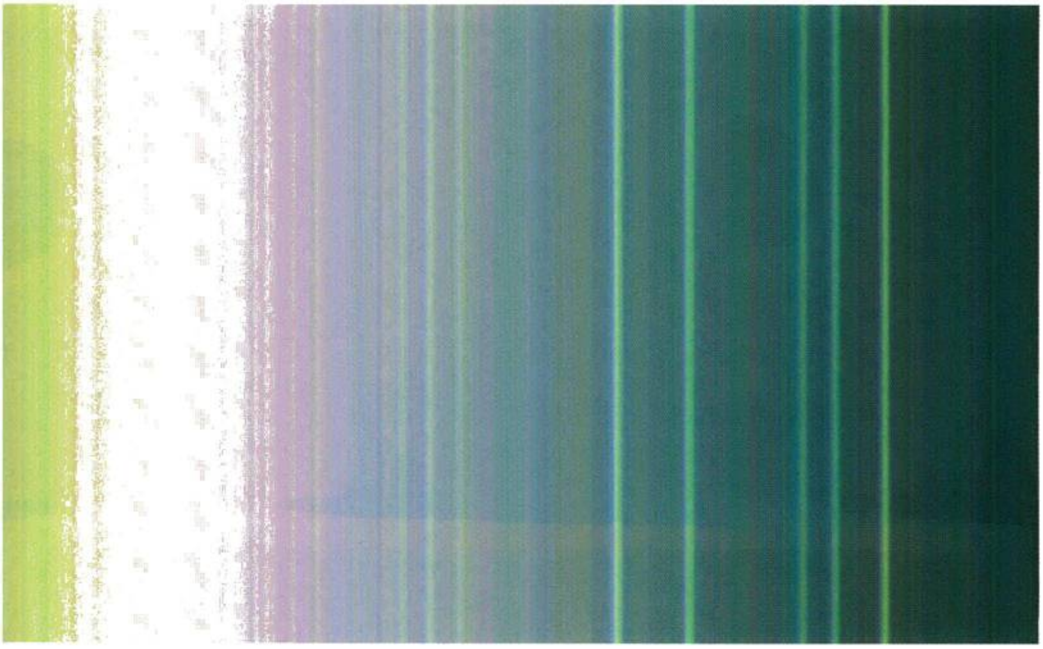
URANIAN RINGS stand out along with a satellite in a view made with the Subaru Telescope's Coronagraphic Imager and adaptive optics. The bluish color indicates methane's dominant presence in Uranus's atmosphere. SUBARU TELESCOPE, NAOJ ◄

49,570 kilometers, slightly smaller than Uranus. Neptune's "year" is 165 years long. Because it is so much more distant — it lies an average distance of 30 astronomical units from the Sun — Neptune is correspondingly smaller and fainter when we view it in telescopes. The composition of Neptune is similar to that of Uranus, with a rocky core, icy mantle, and dense, thick atmosphere composed of many cloud decks. The Voyager 2 spacecraft showed a great surprise at Neptune that it failed to show at Uranus: Neptune displays an incredible variety of weather phenomena. Some of these, such as large cyclone-like storms and groups of high-altitude cirrus, appear almost Earthlike. Others, like Neptune's Earth-sized Great Dark Spot, are not. And the planet's atmospheric temperature is decidedly chillier than Earth's: –220° C. As of this writing, Neptune has 11 moons. The largest of these by far is Triton, which is bright enough to see in



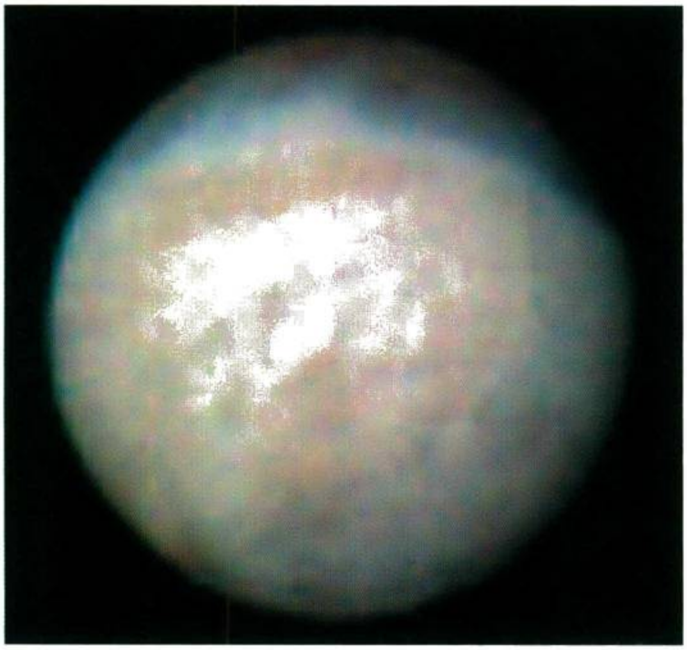
EIGHT MOONS of Uranus stand ▲ out in an image snapped with the Hubble Space Telescope's Near Infrared Camera and Multi-Object Spectrometer. The image was made on July 28, 1997.

ERICH KARKOSCHKA (UNIVERSITY OF ARIZONA) AND NASA



URANUS'S RINGS IN FALSE COLOR ◀ appear startling in an image taken by Voyager 2 on January 21, 1986.

NASA/JPL



NEPTUNE'S LARGEST MOON, TRITON, ► has a wrinkled landscape resembling the skin of a cantaloupe. In this image, Triton's South Pole lies at six o'clock, one-sixth of the way up from the bottom. Voyager 2 created this image on August 20, 1989. NASA/JPL

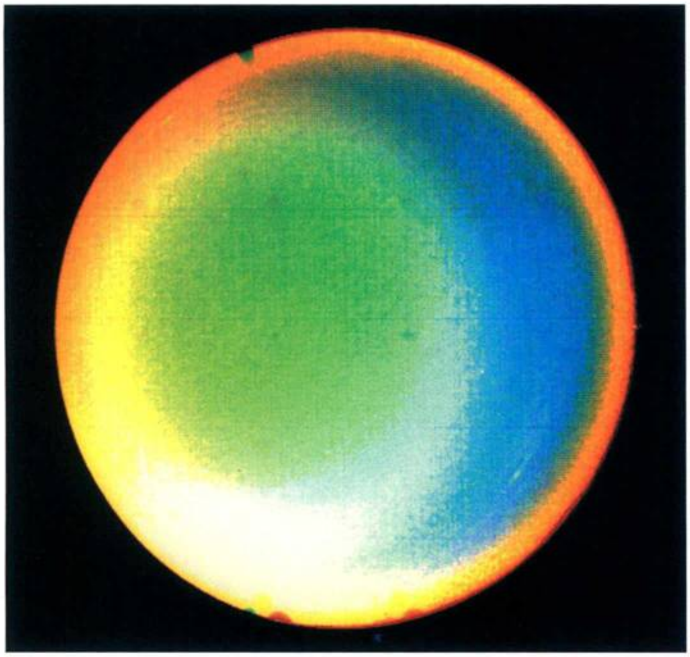
backyard telescopes. The planet itself is slightly brighter than 8th magnitude, making it visible in binoculars and finder telescopes. Like Uranus, it is identified chiefly by its blue color (Neptune appears much bluer than does Uranus.) In telescopes Neptune shows a 2.5-arcsecond disk on which it is not possible to see any detail. Again, with the outer planets, the challenge is simply seeing something that is so remarkably distant.

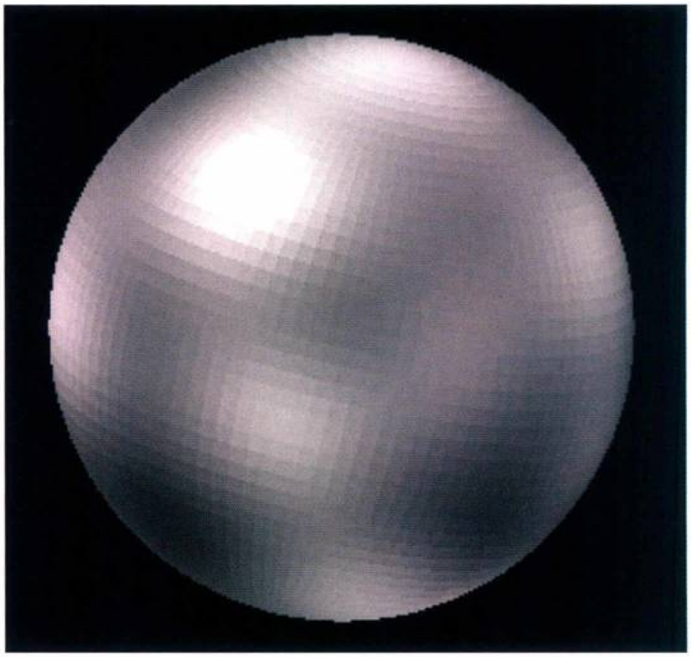
the frozen double planet

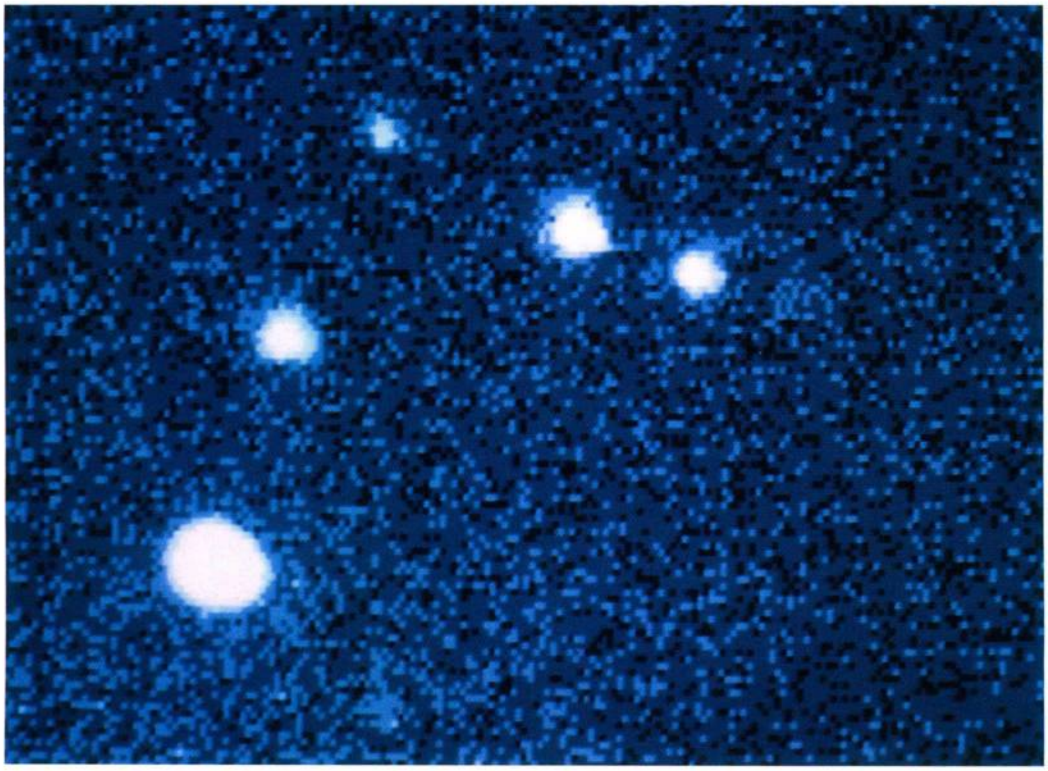
Few planets have remained as mysterious as Pluto, the outermost and most recently discovered. All other planets, except for Pluto, have been visited by spacecraft. In addition, its composition — as much as it can be discerned from Earth-based telescopes — is markedly different from the other outer solar system planets. Rather than a gas giant, Pluto is a small, icy world. Some astronomers believe that long ago the outer solar system was filled with many thousands of Pluto-like bodies, relatively small, icy chunks of matter. Similar objects include Neptune's moon Triton and 1992 QB_1. Between the ancient history of the solar system and today, astronomers believe, the outer solar system was swept mostly clean of these objects and they were pushed out well beyond the orbit of Pluto.

Pluto orbits at an average distance of 39 astronomical units but because its 248-year-long orbit is highly elliptical it is not always the most distant planet. During portions of Pluto's orbit (most recently from 1979-1999) it is actually closer to the Sun than Neptune. The diameter of Pluto is not well established, but is probably about 2,300 kilometers — some half the size of Mercury. In 1978 James W. Christy at the U.S. Naval Observatory discovered a tiny object orbiting Pluto and named it Charon. This small moon orbits Pluto at a distance of 19,400 kilometers and may be fully half Pluto's size, making the Pluto-Charon pair the most equal in size of any planet and moon.

Because its surface temperature is about –230° C, Pluto is too cold







PLUTO'S BASHFUL SURFACE was ▲ finally exposed in this Hubble Space Telescope picture, taken with the European Space Agency's Faint Object Camera. ALAN STERN [SOUTHWEST RESEARCH INSTITUTE], MARK BUIE [LOWELL OBSERVATORY, NASA AND ESA

URANUS'S SMOOTH, BLUE-GREEN ATMOSPHERE ▼ characterizes a spacecraft shot that has been digitally processed. NASA/JPL

TINY PLUTO appears as the ◄ dimmest "star" [upper left] in this CCD field, captured in 1993 by a backyard astronomer. G. FOUTS

to have much of an atmosphere. But when Pluto is closer to the Sun than average, astronomers believe the planet may warm just enough to release gases into a temporary atmosphere that surrounds both Pluto and Charon. The makeup of Charon is similar to that of Pluto: dirty ice.

Pluto is so small and so distant that it is barely observable with backyard telescopes. Still, many amateurs have observed it. At its brightest the planet appears like a faint star of about 14th magnitude, requiring a finder chart to pick it out from the surrounding stars in the field of view. Each year *Astronomy* publishes a star chart showing how to find Pluto for that year. Finding Pluto and identifying it by its slow motion relative to the stars is the ultimate in planet hunting. When you see Pluto in the eyepiece, you'll appreciate why the planet remained undiscovered until the twentieth century.

wanderers of the solar system: comets, asteroids, and meteors

So far we've surveyed virtually all of the solar system: the Sun, inner planets Mercury and Venus, the Earth-Moon system, showpieces Mars, Jupiter, and Saturn, and the outer planets Uranus, Neptune, and Pluto. These major planets, along with their moons and our Sun, constitute the main pieces of the solar system. But they do not make up the whole solar system. Other, smaller chunks of rock and ice float about the Sun in a variety of orbits and round out our understanding of how the solar system works.

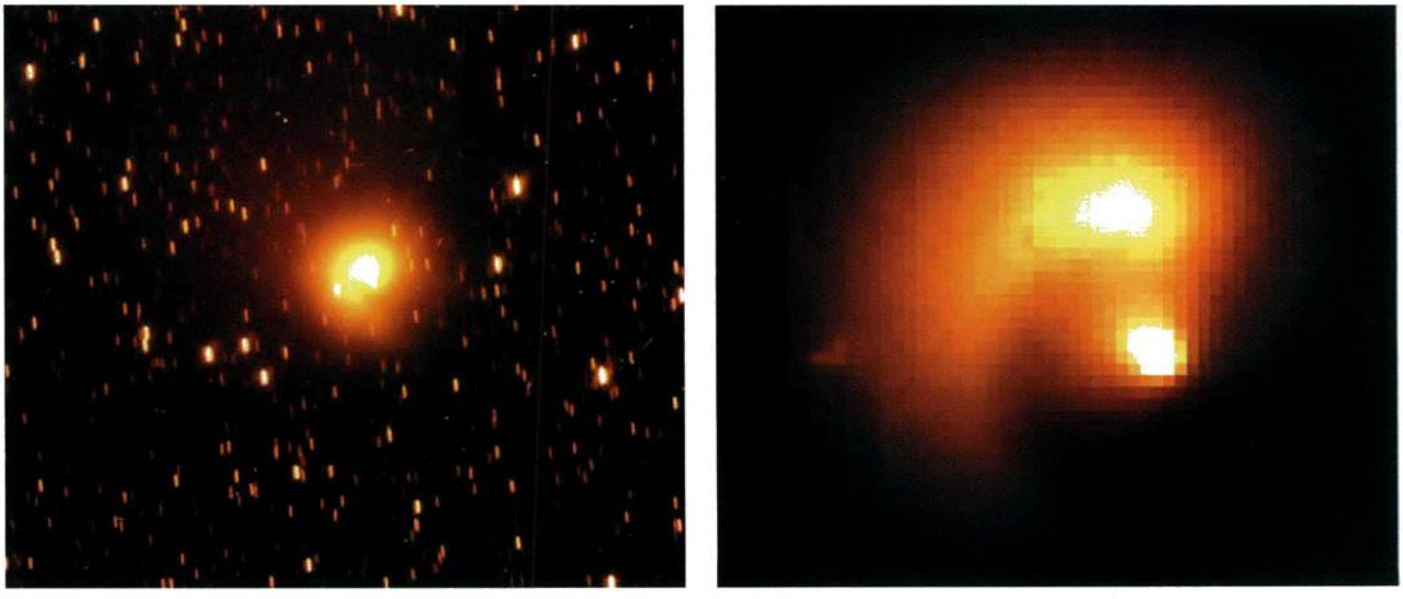
The micromatter in our solar system shows up in a variety of different species. Comets are chunks of dirty ice that live deep in the outer solar system. Although most comets exist far beyond our ability to see them and stay in a permanent deep freeze, some comets approach the Sun closely enough that they heat up on occasion and produce glowing tails. Asteroids, or minor planets, are chunks of rock that orbit far from the Sun — many in a zone between Mars and Jupiter — and range in size from 1,000 kilometers across down to the size of a refrigerator. Asteroids usually wander harmlessly as they circle the Sun, yet an asteroid impact on Earth 65 million years ago likely killed many life-forms, including the dinosaurs, and at some future date astronomers predict that an asteroid will hit Earth again.

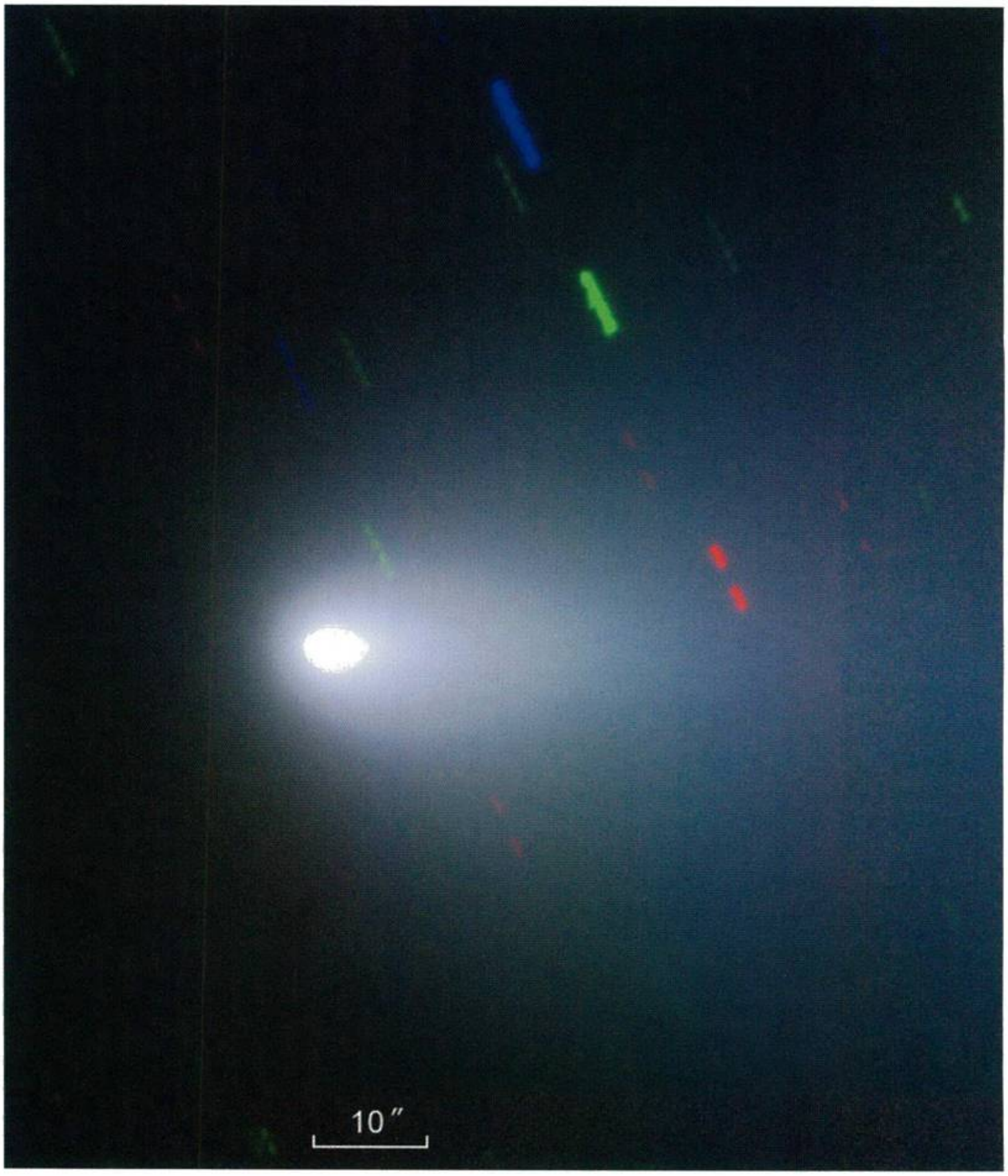
With very little effort, the smallest particles in the solar system can be seen in Earth's atmosphere as they enter, heat up, and vaporize. Watching such meteors — "shooting stars" — makes a pleasant evening activity. All that's required is a comfortable reclining chair, a tasty beverage, and insect repellent.

Most of these particles are no larger than a grain of sand. Large particles that make it all the way down to strike Earth's surface are called meteorites. Other phenomena related to small solar system particles can also be observed. The

THE MAGNIFICENT C/1965 S_1 ► IKEYA-SEKI paints a quill pen-like streak across the sky in this 1966 image. Ikeya-Seki was named after the two amateur Japanese comet searchers who found it. ROGER LYNDS/NOAO/AURA/NSF

COMET C/1995 O_1 HALE-BOPP ▼ [both images] showed a pinwheel pattern of flying debris around its center as it neared the Sun in 1997. The spiral pattern resembles that of a backyard sprinkler. The comet's solid center rotates about once per week, dispersing debris as it spins. H. A. WEAVER (APPLIED RESEARCH CORP.), P. D. FELDMAN (THE JOHNS HOPKINS UNIVERSITY), AND NASA





COMET C/1999 S_4 LINEAR was discovered on September 27, 1999, by the Lincoln Near Earth Asteroid Research project. This Subaru telescope image clearly displays LINEAR's head and tail as it treks across the sky. Stars appear as streaks because Subaru moved to follow the comet.

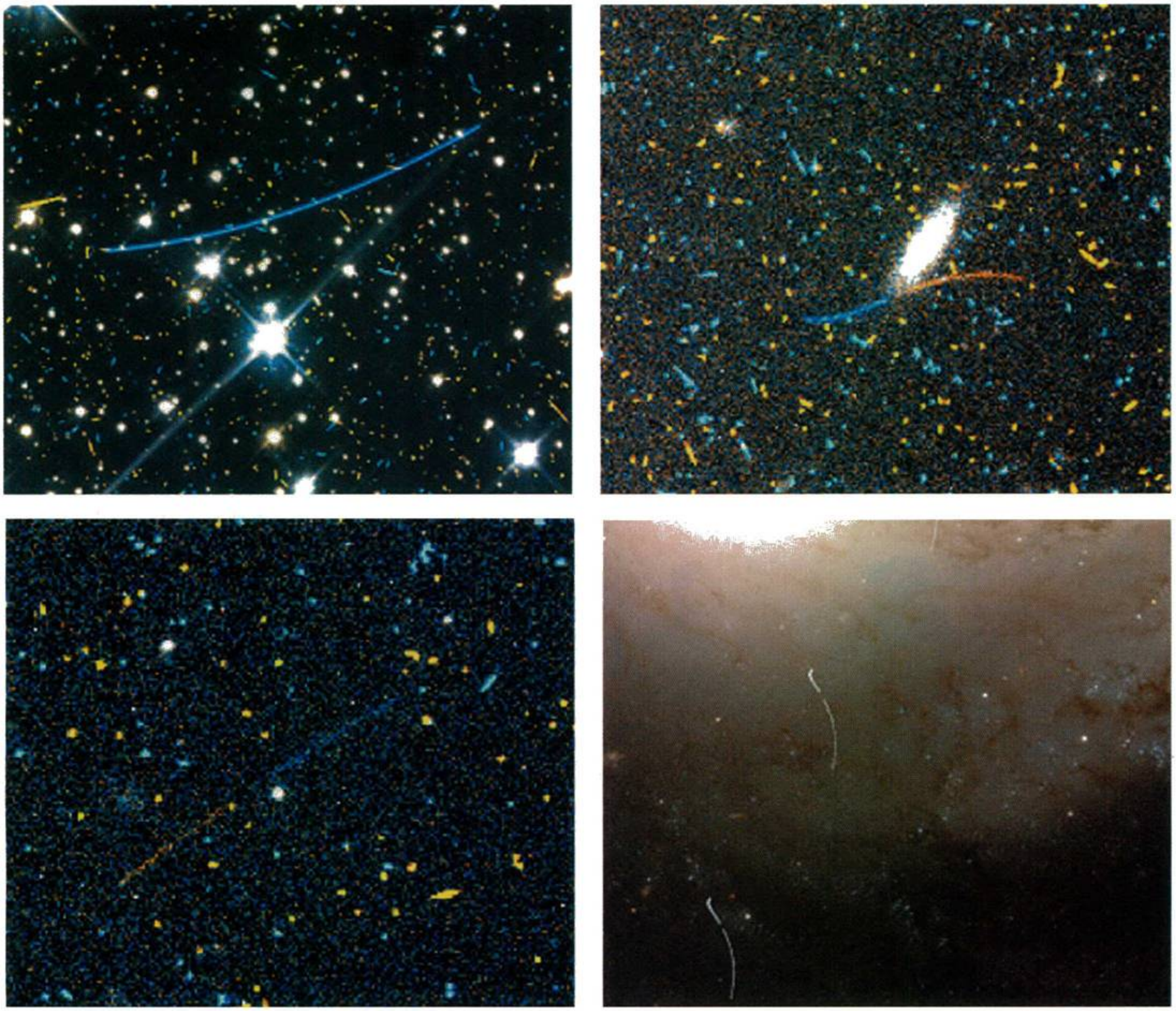
SUBARU TELESCOPE, NAOJ

zodiacal light is a subtle brightening visible along the ecliptic, the apparent path of the Sun across the sky. It is caused by sunlight scattering off small particles in the plane of the solar system. It may be seen as a triangular patch of light beginning at the sunset point in the west (or the sunrise point in the east in the morning sky) and extending halfway or more to the overhead point. If your sky is very dark, the zodiacal light can seem quite bright.

Even harder to spot is the gegenschein, or counterglow, a faint spot of light caused by particle-scattering directly opposite the Sun's position in the sky. The easiest times to see this elusive phenomenon are during March or September, when the gegenschein is located far from the band of light we call the Milky Way. Finally, energetic particles from the Sun itself enter Earth's magnetic field, spiral inward, and speed up, creating a ghostly glow called the aurora. The effect is best visible after a solar storm from a spot near Earth's North Magnetic Pole (aurora borealis, or northern lights) or South Pole (aurora australis, or southern lights).

icy mudballs in the frozen deep

For centuries comets have been one of the most awe-inspiring sights in nature. Taken by early skywatchers as portents of doom or impending change, comets are in fact frozen solar system garbage left over from the accretion of the major planets. As chunks of frozen mud and ice, the nucleus of a comet — the permanent, solid part — probably measures a few kilometers across, the size of a small city. Comets contain two other distinct parts, particularly when they stray relatively close to



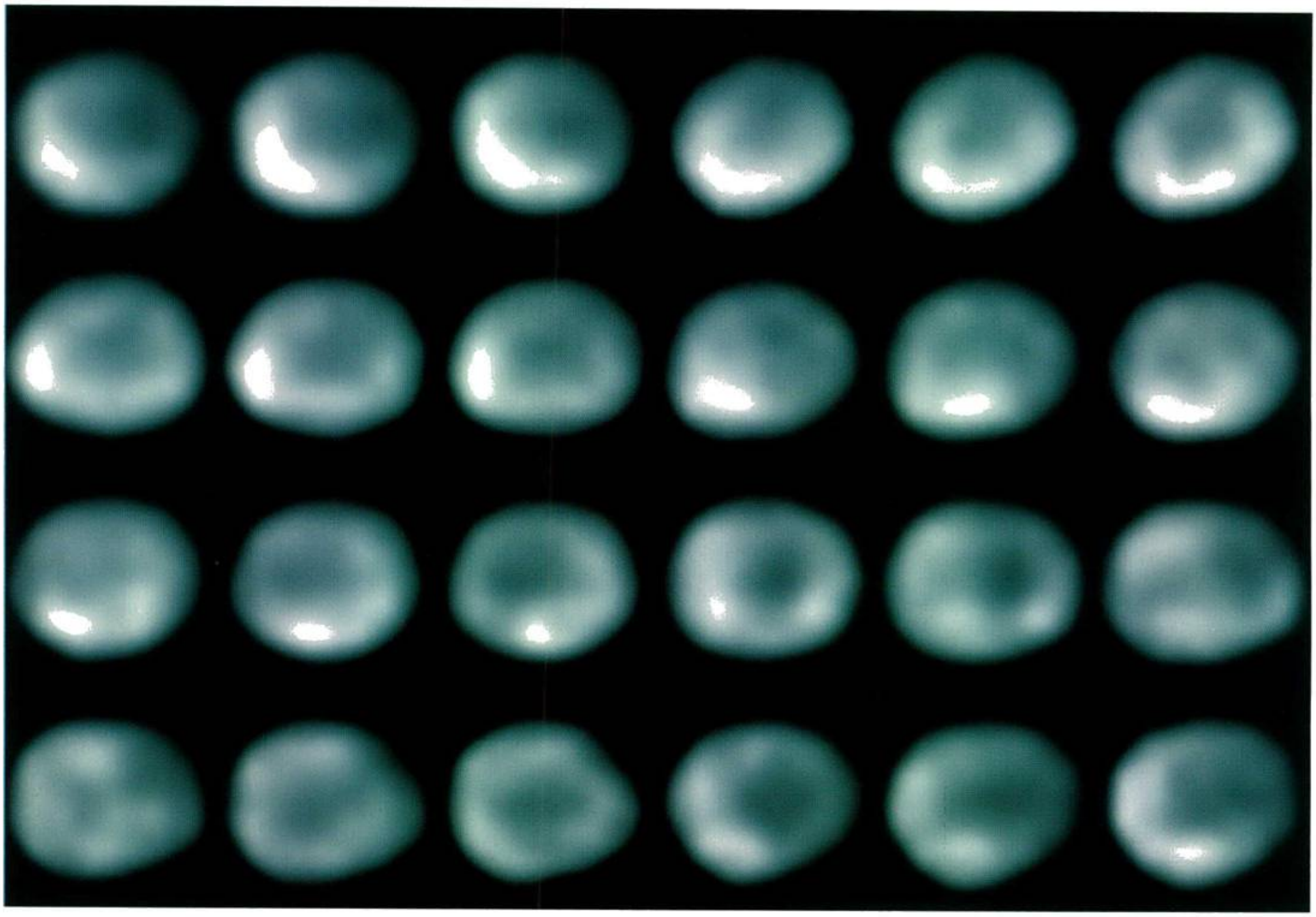
ASTEROIDS CAUGHT ON FILM! Astronomers Karl Stapelfeldt and Robin Evans sifted through more than 28,000 images taken by the Hubble Space Telescope's Wide Field and Planetary Camera 2. These four images of asteroids are just a sample of the approximately 100 small asteroids the two men discovered.

R. EVANS AND K. STAPELFELDT (JPL), NASA

the Sun and warm up. These are a coma, an extended halo of particles vaporizing from the nucleus, and a tail, a stream of dust and ionized gas from the nucleus that always points away from the Sun. The Sun's radiation and its solar "wind" of energetic particles push away material from the cometary nucleus. A comet's tail can stretch for millions of kilometers, although its density is very low.

Comets orbit the Sun in two broad classes, long-period comets and short-period comets. Short-period comets have periods of 200 years or less. Most of them lie within the orbits of the nine planets and indeed were drawn into the solar system by the gravitational effects of the planets. Long-period comets have elliptical orbits with much longer periods — up to millions of years— and some of them indeed come close to the Sun and are catapulted away never to return. Astronomers believe that most comets exist in the Oort Cloud, a spherical stockpile of cometary nuclei far beyond the orbit of Pluto. (The feature was proposed by the Dutch astronomer Jan Oort.) This is the residence of long-period comets, which occasionally through the tug of gravity get kicked in toward the Sun. Short-period comets probably reside in the Kuiper Belt.

The most famous of all comets is Halley's Comet, which last approached the Sun in 1985/1986. Unfortunately, the orbital geometry of Earth, comet, and Sun was arranged so that the comet did not become as bright as it had on many previous apparitions. Halley's 76-year period will bring it into view again in the year 2061, when it will be brighter and more easily seen. Another notable comet, Swift-Tuttle, was recovered



HUBBLE IMAGED THE ASTEROID VESTA, providing astronomers a view of some of the oldest terrain in the solar system. Fragments of Vesta, detached from the asteroid after many collisions, have fallen to Earth as meteorites. Astronomers have samples from only three other solar system objects: Earth, the Moon, and Mars.

B. ZELLNER (GEORGIA SOUTHERN UNIVERSITY), NASA

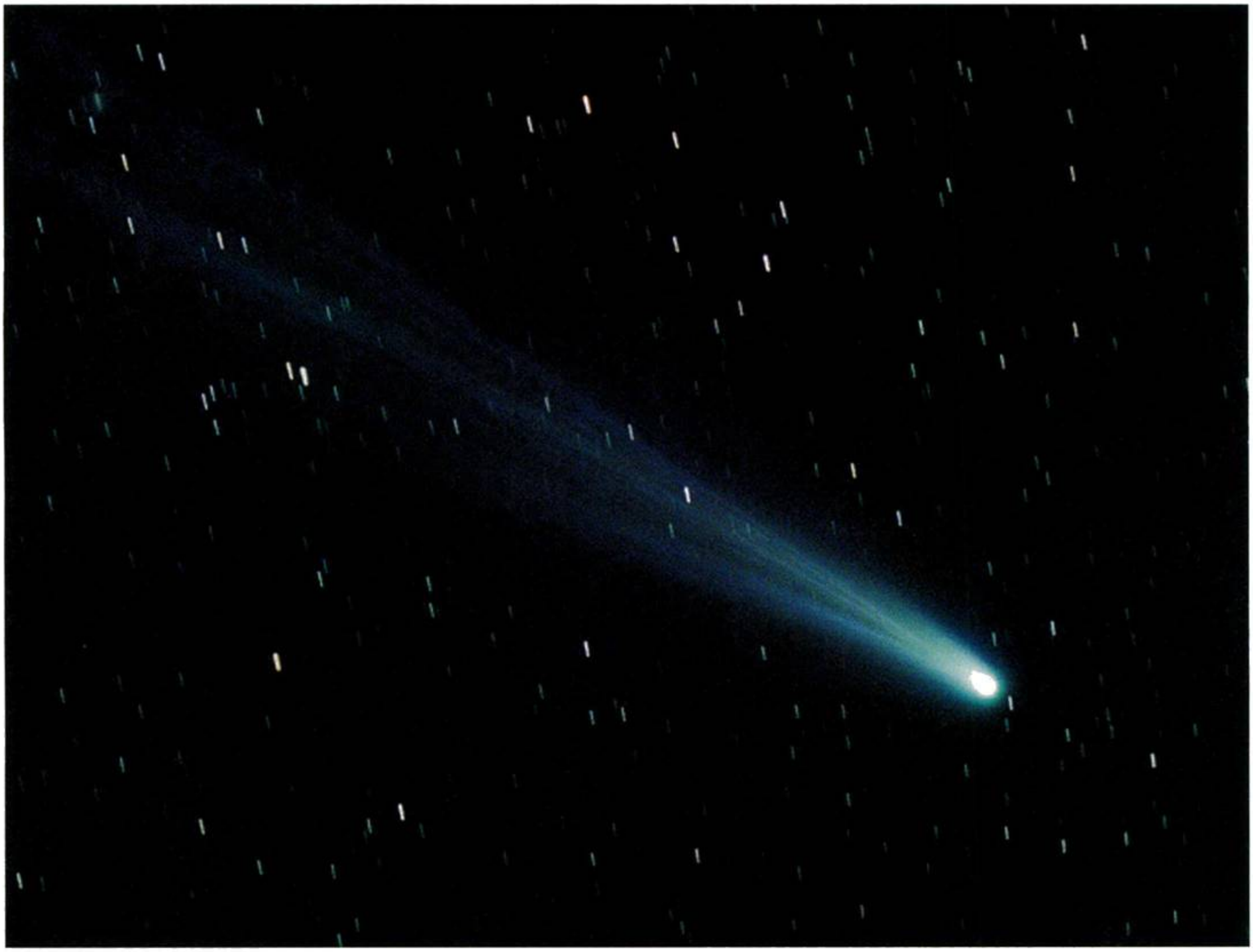
in 1992 after 130 years. This comet is the parent of the famous Perseid meteor shower, which is visible every August. The last spectacular comet, Comet Hale-Bopp, appeared in 1997, and was easily visible for several months. Shining at magnitude –1 and with a tail that stretched across many degrees on the sky, the comet was a striking sight to the unaided eye. Millions of people enjoyed Hale-Bopp in the spring of 1997. Of course, nobody can say when we're due for another bright comet, but one could appear at any time.

Several times during each year telescopic comets may become visible. They may not be impressive naked-eye sights, but many comets in the 8th-10th magnitude range show a fuzzy coma and a short tail when viewed with even a 3-inch telescope at low power. Consult the latest Astronomy magazine, or visit Astronomy.com to see if any comets are currently visible in the night sky.

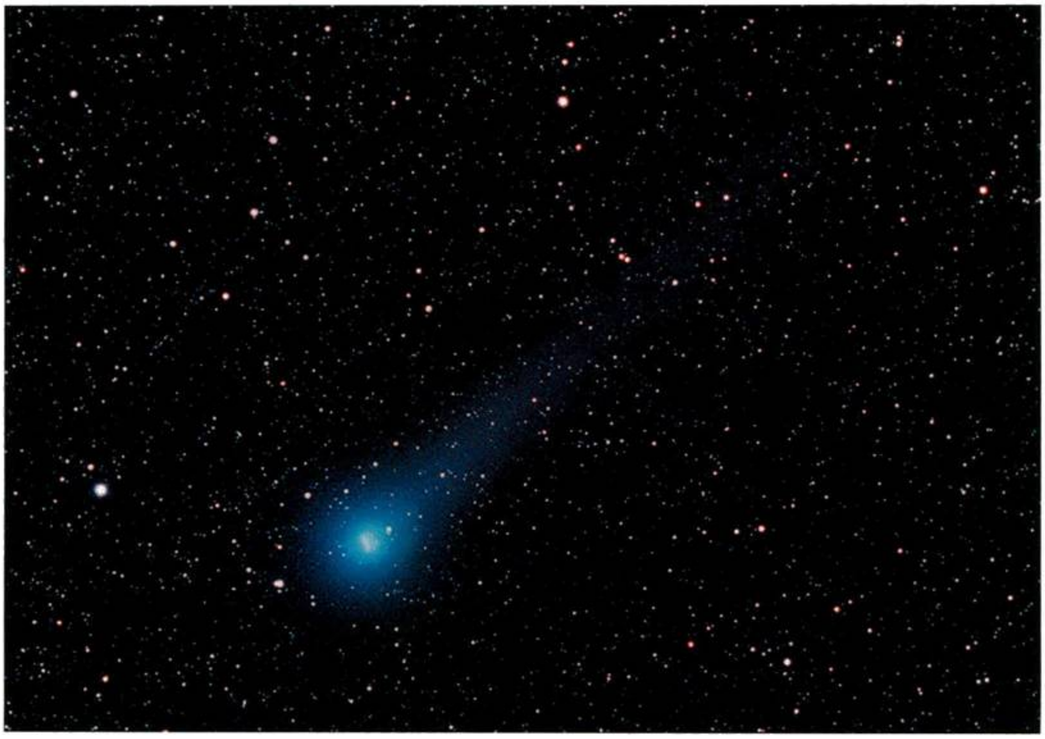
the orbiting rocks

Asteroids are solar system debris like comets, but they differ from comets in fundamental ways. They are rocky and practically all of them, perhaps 95 percent, orbit in a disk situated between Mars and Jupiter — at distances of 2.2 to 3.3 astronomical units — called the main asteroid belt. Like planets, most of these main belt asteroids have orbits that are nearly circular. As of this writing, astronomers believe that several hundred thousand asteroids may exist within the main belt. They have already discovered and named about 35,000, and several thousand more exist with well-known orbits. In all likelihood asteroids are the debris from a group of miniplanets that once existed between Mars and Jupiter but fragmented in a series of collisions.

The first discovery of an asteroid came on January 1, 1801. On that New Year's Day the Italian astronomer Giuseppe Piazzi found 1 Ceres, which turns out to be the largest asteroid with a diameter of 1,000 kilometers. Notice that when an asteroid is named, there is usually a number preceding it. This number used to indicate the order of discovery, so 1 Ceres was the first asteroid discovered. Today, however, the number indicates when the orbit was officially determined. This can be several years after the initial discovery of the asteroid. Thus, an asteroid with a high number such as 3617 Eicher was numbered and named only after its orbit was determined to a high degree of accuracy. The

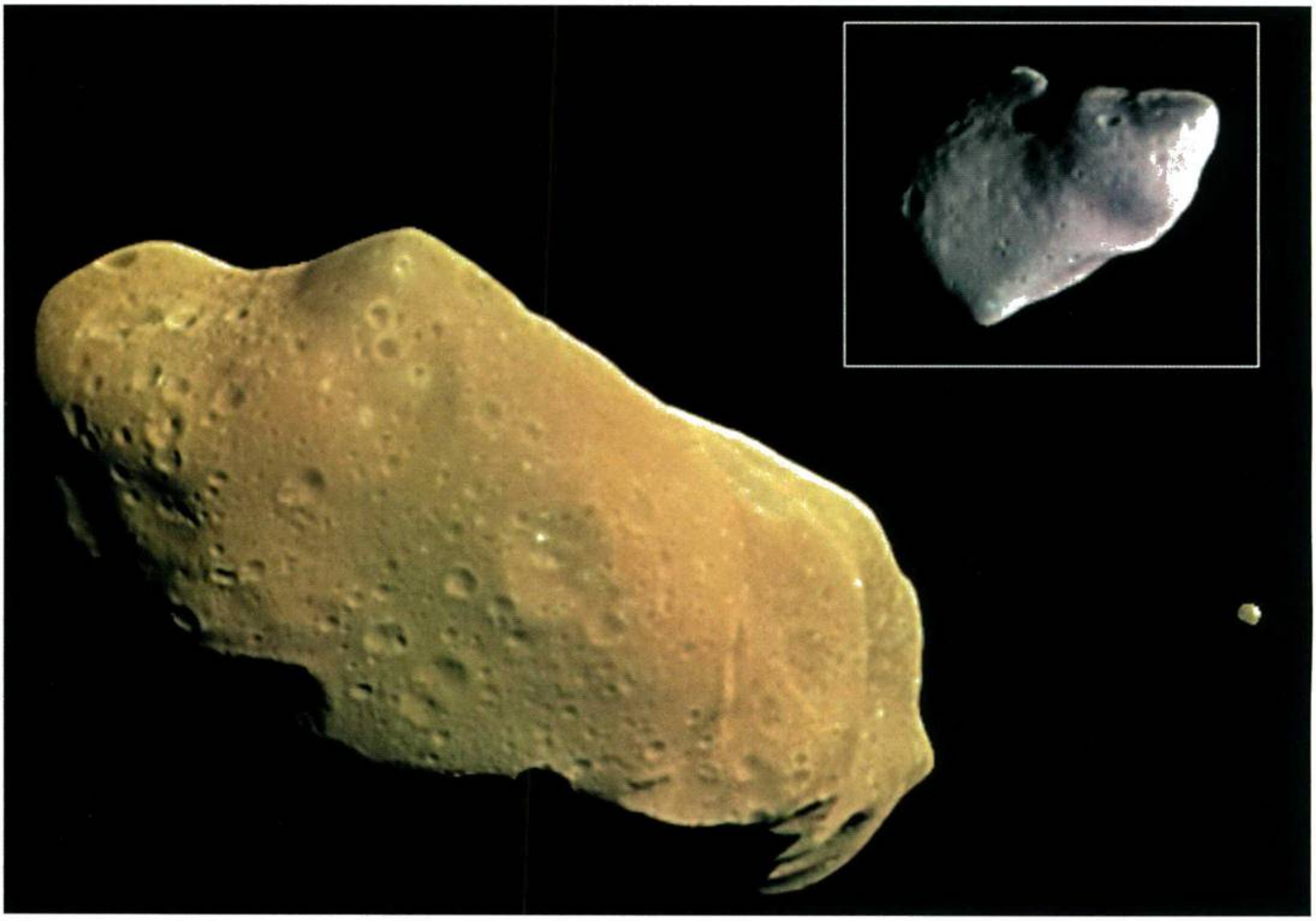


THE BEAUTIFUL COMET C/2002 C$_1$ IKEYA-ZHANG blazes across the sky, leaving a long, wispy trail in its wake. Chris Cook shot this 25-minute exposure using a 102mm f/8.6 apochromatic refractor at f/6.9. CHRIS COOK



THE GLOWING BLUE BALL of Comet C/2001 A2 LINEAR rolls across the night sky in this 35-minute exposure taken by Chris Cook. The Californian used a 102mm f/8.6 apochromatic refractor at f/6.9 and hypersensitized Kodak Ektapress PJ400 film.

CHRIS COOK



ASTEROID IDA'S TAGALONG, Dactyl, faithfully follows its larger cousin in this image from the Galileo spacecraft. Dactyl is the first confirmed satellite of an asteroid; it appears to the right in the image and is magnified in the box.

NASA/JPL/USGS

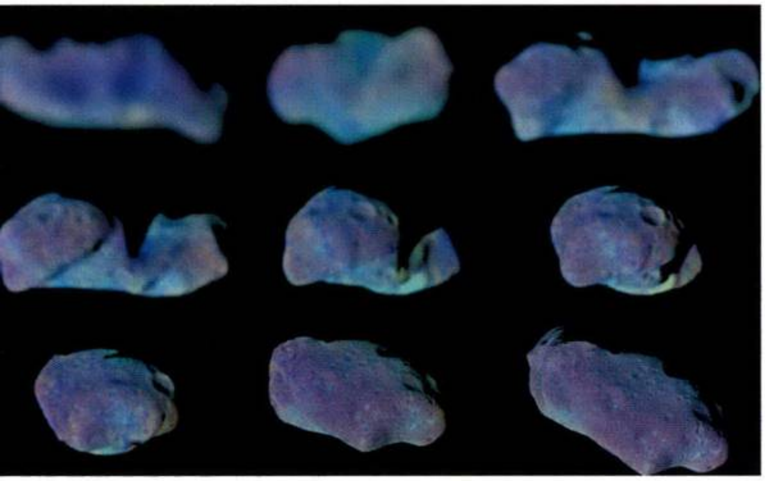
discovery of Ceres opened up a new age of solar system exploration during which many other astronomers searched for and found other asteroids. The most famous of these are the "big four": Ceres, 2 Pallas (discovered in 1802; 540 kilometers), 3 Juno (1804; 247 km), and 4 Vesta (1807; 515 km). Most asteroids are much smaller than these, however; only 200 exceed 100 kilometers in diameter.

The brightest asteroid, Vesta, is just visible to the naked eye. But realistically the brightest few are best visible in small telescopes. The small diameters of asteroids make them appear starlike in earthbound telescopes. The brightest glow at 6th and 7th magnitude, and many dozens are in the comfortable range of backyard observing at 10th to 12th magnitude. Because they appear stellar, asteroid observing is a little tricky. You must identify the field of view in which an asteroid lies, make a quick sketch of the field, and come back much later during the night (or the following night) and resketch the field. The "star" that has moved relative to the background stars is not a star, but the asteroid.

Not all asteroids (and comets, for that matter) have innocent orbits. Over spans of time of millions and billions of years, many solar system rocks will come close to or intersect the orbits of other asteroids, comets, or even planets. The evidence of impacts in the solar system is abundantly obvious on the Moon, Mercury, and other impact-scarred planets and moons. Earth, indeed, wears its own scars from long-ago impacts, such as the Barringer Meteor Crater in Arizona. Unlike barren worlds, however, Earth's active weather system helps to cover up old scars. The message is clear, however: Although much of the debris of the early solar system is gone, impacts will occur in Earth's future. The difference between the future and the past, however, may be that earthlings now have the technology to discover objects on a collision course with Earth and gently alter their orbit, turning a direct hit into a miss.

raining pebbles on Earth

Rocky particles much smaller than asteroids abound in the solar system. They float calmly around the Sun in the millions. Sources of these microparticles include asteroid collisions that send small packets of debris into odd orbits, and the trails of comets, whose particles stream off the cometary nuclei and accumulate in their orbits. When Earth crosses into the orbit of a comet or when scat-



STRIKING IMAGES OF ASTEROID IDA emphasize color contrasts on the asteroid's surface. Looking as if they were shot under a black light, the images were taken through 4100-angstrom, 7560-angstrom, and 9680-angstrom filters. NASA/JPL/USGS ▼

COLOR IMAGES OF EROS were recorded by NEAR-Shoemaker, the first spacecraft to land on an asteroid, over a five-and-a-half-hour interval prior to touchdown. NASA/JPL/JOHNS HOPKINS UNIVERSITY, APPLIED PHYSICS LABORATORY ▲

tered debris falls into Earth's atmosphere, the small particles are pulled in by Earth's gravity and burn up due to friction. As the particles burn up, one of the energy byproducts is light, so we see them as meteors, brief flashes of light that streak across the sky.

Meteor watching is one of the most enjoyable aspects of amateur astronomy. It requires nothing but a chaise longue or sleeping bag on which to sit or lie and a steady gaze up at the sky. Random, or sporadic, meteors are visible on every clear night, but meteors are visible in greater numbers during so-called meteor showers. These occur when Earth's orbit intersects a stream of debris and we can see many meteors per hour.

Twenty principal meteor showers have been identified. During a shower the meteors appear to come from a radiant, a particular point in the sky, but the meteors can streak across in any direction from that point. By far the best time to observe meteors during any shower (or on any random night) is between local midnight and dawn, when Earth's rotation turns it head-on into the approaching cloud of debris.

A meteor shower is named for the constellation that contains its radiant. So, if the radiant lies in the constellation Leo, the shower is known as the Leonids. Some constellations have more than one shower, and the name usually reflects the nearest bright star to the radiant — as the Northern Delta Aquarids in the constellation Aquarius. One of the earliest meteor showers of the year is the Quadrantids. Its peak occurs around January 4. Notice that the first shower listed is the Quadrantids. You might wonder about that name, and you'd be right to do so. This shower's name does indeed follow the rule above; however, the constellation that it is named for, Quadrans Muralis, no longer exists. The most popular meteor shower is the Perseids,

PEERING INTO THE DEPTHS of a giant crater of Asteroid Eros. The crater measures 3.3 miles (5.3 km) in diameter. NEAR-Shoemaker shot this image from an altitude of just 31 miles on June 14, 2000. Color images were made to measure the properties of the regolith inside the asteroid's craters. NASA/JPL/JOHNS HOPKINS UNIVERSITY, APPLIED PHYSICS LABORATORY ◄

COMET HALE-BOPP blazes ▲ across the sky on April 4, 1997. Michael Stecker shot this 20-minute exposure with a 130mm f/6 refractor and Kodak Pro 400 film. MICHAEL STECKER

THE 2001 LEONID METEOR SHOWER ► revealed bursts of meteor streaks to patient observers and photographers. Tony and Daphne Hallas recorded this image with a 35mm f/2 lens and Fuji 800 film. TONY AND DAPHNE HALLAS

A STUNNING COMPOSITE of the ▼ 1998 Leonid Meteor Shower was captured by Tony and Daphne Hallas using a 6x7 cm camera and hypered Kodak PPF 120 format film. TONY AND DAPHNE HALLAS

THE GREAT COMET OF 1997, ▲ Hale-Bopp, unzips its way through space in this Chris Cook image. Cook captured this 8-minute exposure using a 200mm f/4 lens with Fujicolor Super G 800 plus film. CHRIS COOK

probably because it occurs in midsummer and is notable for its bright meteors that leave glowing trails visible for several seconds.

Almost all meteors that enter Earth's atmosphere burn up long before reaching Earth's surface. Those few meteors that survive to strike Earth are called meteorites, and many thousands exist. Some amateur astronomers have become ardent meteorite collectors, in fact. Meteorites exist in two principal types, stony and nickel-iron.

strange lights in the night sky

Some solar system particle debris interacts with the night sky in more subtle ways. One of the most stunning spectacles in the sky is a bright aurora, a dancing, shimmering display of greenish, yellowish, or even ruddy light that may be visible in the northern sky or spread all across the sky's dome. (South of the equator the aurora is visible in the direction of the south pole.) Aurorae can be very subtle or startlingly bright. One of the most striking aurorae in recent times was visible on the night of November 8, 1991, when Northern Hemisphere observers saw the entire sky explode in a cinematic upheaval of curtains, pillars, streaks, coronae, rays, and other bright, well-defined, and multicolored glows. Aurorae result from bursts of solar particles that enter Earth's magnetic field and interact with atmospheric molecules, giving off light as they spiral down toward the poles at super high speeds.

Other haunting skyglows are more subtle. The zodiacal light is a diffuse band of milky light that is visible only under a dark sky. Caused by sunlight scattering off dust particles in the plane of the solar system, the zodiacal light starts at the sunset or sunrise point and stretches across the ecliptic, the apparent path of the Sun on the sky. A similar phenomenon is the gegenschein, or counterglow, which is a subtle glow on the sky opposite the position of the Sun. These subtle effects are rather difficult to observe, and you may have to wait for an exceptionally clear, dark sky to see them.

stars: single, double, and variable

Stars are hard to ignore in the framework of human consciousness. We attach such dramatic emotions to them — mystery, romance, suspense, an aura of the unknown and the infinite. On any clear night we can gaze up at the sky and see thousands of stars, so bright and seemingly so close yet in reality astonishingly distant. The human fascination with stars is hardly new, certainly having existed since the first high-order mammals looked skyward. Yet only in recent times have astronomers made substantial headway in figuring out exactly how stars form, live, and die.

Stars are the basic "units of matter" in the universe. They are energetic balls of mostly hydrogen gas that slowly fuse their material into heavier elements until one day they exhaust the fuel supply and end their lives. The Sun is of course the closest star, the powerful source of energy in our solar system. As we've seen in a previous chapter, the Sun is a rather average star. Stars exist in many sizes, temperatures, colors, and chemical compositions, each allowing astronomers to piece together a little part of our knowledge about the universe.

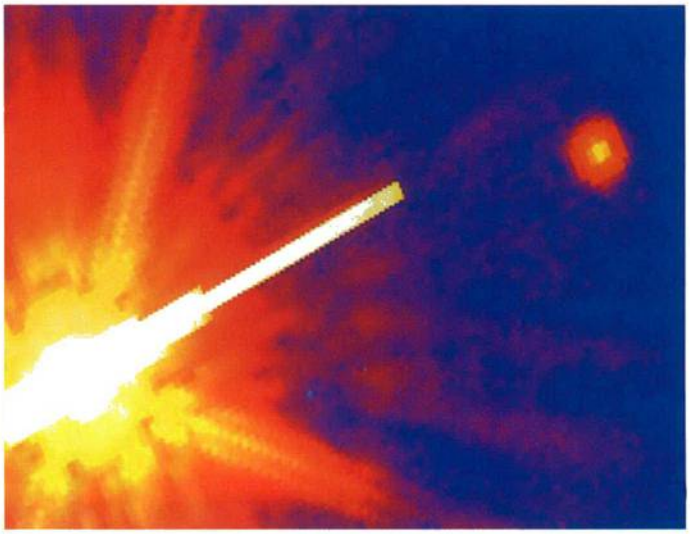
THE RHO OPHIUCHI COMPLEX ► shows up in multicolors in this Tony and Daphne Hallas image. The region of molecular and dark clouds and emission and reflection nebulae surrounding the star Rho Ophiuchi contains more color than any other in the sky. This image was made with a 4-inch f/6 refractor and Kodak PPF 400 film. TONY AND DAPHNE HALLAS

a galaxy filled with stars

Astronomers classify stars in many ways, the most basic being by color. Stars are classed into spectral types along a continuum from blue to white to yellow to orange to red, as follows: O and B (blue), A and F (white), G (yellow), K (orange), and M (red). Color and temperature are directly related: the hotter the star, the bluer it is. Red stars are relatively cool. The Sun, as we've seen, lies in the middle as a yellow-white G-type star.

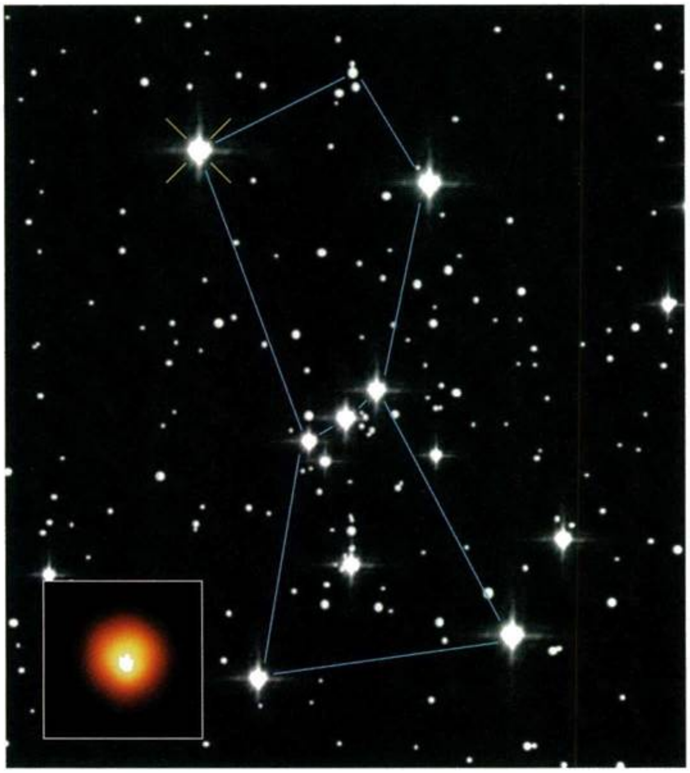
Examples of the range of star colors can be seen with the naked eye on any clear night. Rigel (Beta Orionis), the 0-magnitude star marking Orion's left foot, is a B star. Nearby Sirius (Alpha Canis Majoris), the brightest star in the sky, is an A star. Zero-magnitude Procyon (Alpha Canis Minoris) is an F star. Zero-magnitude Capella

SHINING COLORFULLY, the star ▼ cloud NGC 206 in the Andromeda Galaxy was captured by Tony and Daphne Hallas. The image was created with a 14.5-inch Cassegrain scope and an SBIG ST10E CCD camera. TONY AND DAPHNE HALLAS



AN INCREDIBLY COOL STAR is ◀ born (upper right) in this Hubble Space Telescope image. Along with the K dwarf star called GL 105A, seen at lower left, the lightweight star, GL 105C, lies 27 light-years from Earth within the boundaries of the constellation Cetus.

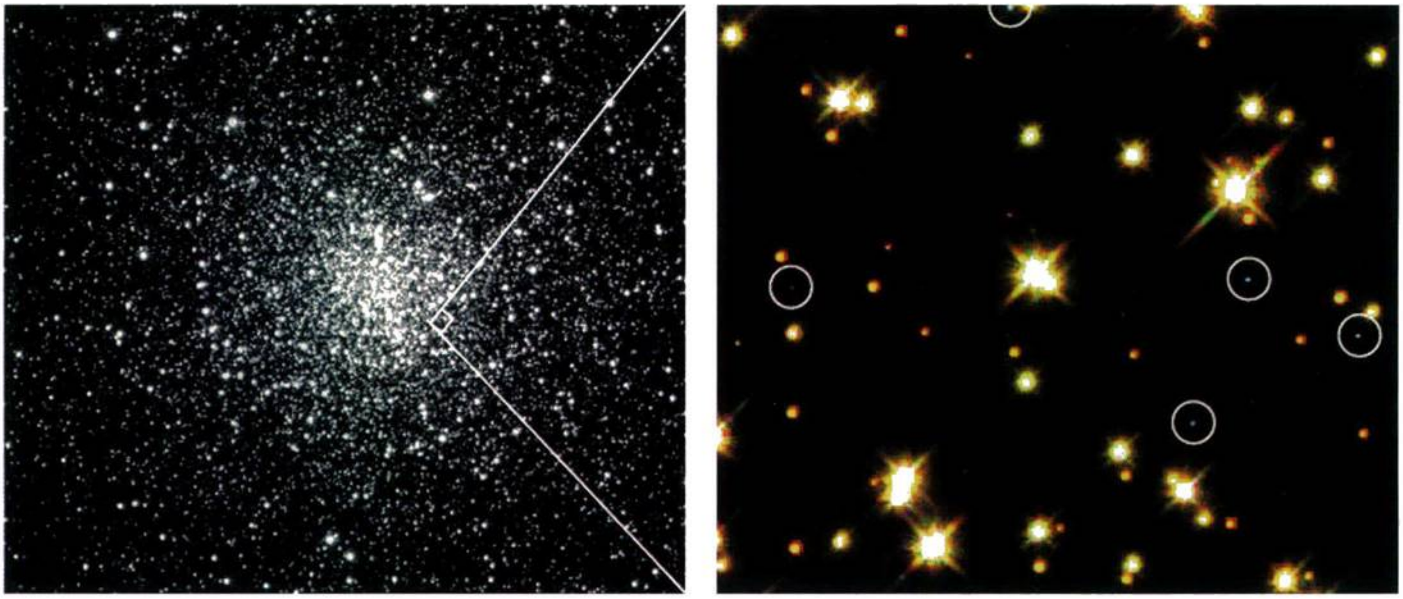
D. GOLIMOWSKI (JOHNS HOPKINS UNIVERSITY), AND NASA



THE FIRST DIRECT IMAGE of a ▲ star other than the Sun reveals the face of Betelgeuse in Orion. Hubble captured the image of this red supergiant as it nears life's end; the star could catastrophically explode as a supernova in the near future. ANDREA DUPREE (HARVARD-SMITHSONIAN CFA), RONALD GILLILAND (STSCI), NASA AND ESA

THE BOW SHOCK AROUND ◀ **LL ORIONIS** glows brightly as a result of interplanetary matter moving at supersonic speeds relative to Earth. Like the Concorde racing across the sky faster than the speed of sound, this material builds up a shock front that causes gas to glow like a fluorescent light. HUBBLE HERITAGE TEAM; HUBBLE SPACE TELESCOPE; AND STSCI

DISCOVERED BY FERDINAND ▶ **MAGELLAN,** the Magellanic Clouds are close neighbors to our own Galaxy but are visible only from the Southern Hemisphere. The Large Magellanic Cloud, seen here, resides in the constellation Dorado. HUBBLE HERITAGE TEAM (NASA/AURA/STSCI)



A CELESTIAL GRAVEYARD exists ▲ in globular cluster M4 in Scorpius, which is littered with white dwarf stars. This image, made with the Hubble Space Telescope, captured individual stars having a brightness equivalent to a 100-watt light bulb seen from the distance of the Moon. HARVEY RICHER (UNIVERSITY OF BRITISH COLUMBIA, VANCOUVER, CANADA), AND NASA

ORION'S BRILLIANT RIGEL, the ◄ 7th brightest star in the sky, is a blazing white-hot supergiant thousands of times more energetic than the Sun. LEE C. COOMBS

(Alpha Aurigae) is a G star like our Sun. First-magnitude Aldebaran (Alpha Tauri) is a K star. First-magnitude Betelgeuse (Alpha Orionis) is an M star. A longstanding mnemonic helps astronomers remember the sequence of spectral letters: "O Be A Fine Girl (or Guy), Kiss Me!"

Many of the stars visible to the naked eye are nearby stars in our galaxy, several hundred light-years away. All stars visible in backyard telescopes are members of our galaxy. Astronomers further separate stars by their luminosity classes, which broadly define stars as supergiants, giants, or dwarfs. Most stars are dwarfs, or so-called main sequence stars. Although the Sun lies in the midst of the main sequence, with a diameter of 870,000 miles, an average luminosity, and a surface temperature of 6,000° C, stars exist that are much cooler, much hotter, much brighter, much dimmer, much larger, and much smaller.

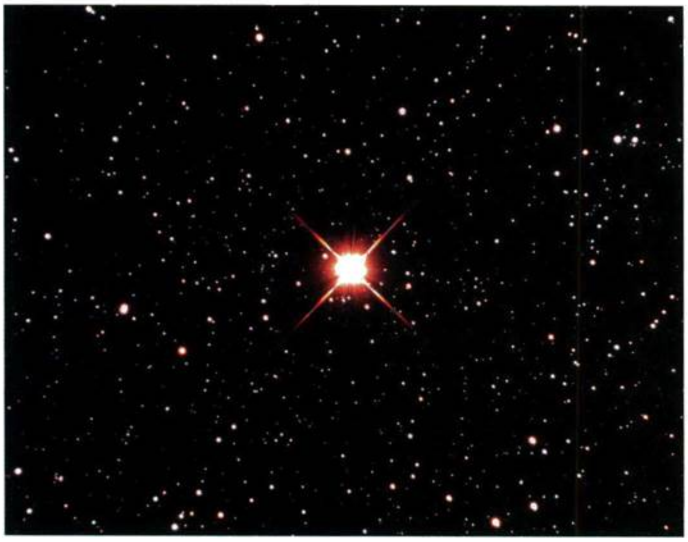
At the extreme limits of a star's existence, some supergiants span hundreds of millions of miles, shine with the light of several thousand suns, and have surface temperatures of 30,000° C. White dwarfs, on the other hand, are extremely dense, burned out stars that have stopped all nuclear fusion, collapsed on themselves and are no larger than Earth, emitting a tiny fraction of the Sun's light. These are different than red dwarfs, the normal dwarfs that are scattered along the main sequence.

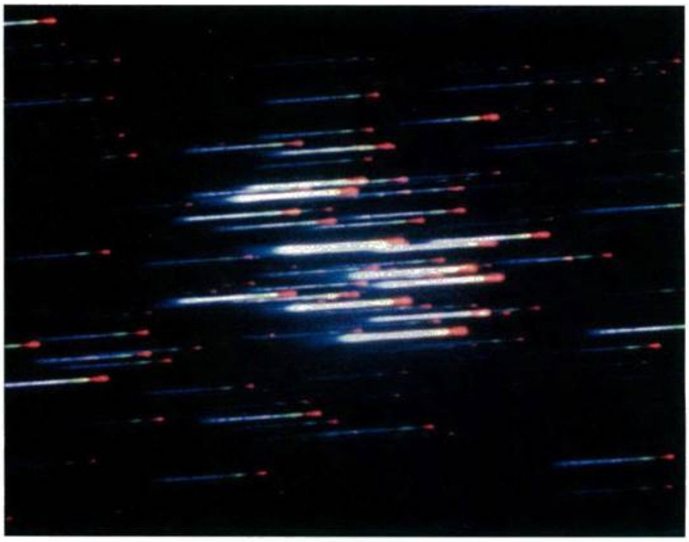
Although the Sun lies in the middle of the scheme of things, slow-burning red dwarf stars vastly outnumber "middle-of-the road" stars, giants, and supergiants. Statistically, then, the Sun is a better-than-average star.

double and multiple stars

Although the Sun is a single star, a casual scan of the sky with a telescope will show that many stars seem to exist in pairs or multiple systems. A few of these objects are simply chance alignments of stars that actually lie at vastly different distances. These are called optical double stars. However, many stars do live in twin, triple, or quadruple systems that are physically bound by gravity and travel through space in orbit around a common center of mass. Astronomers call these objects binary stars and multiple stars. Curiously, binary and multiple systems outnumber single stars in our galaxy by a substantial fraction, making up about 60 percent of all observed stars.

Binary stars allow astronomers to study many properties about stars that otherwise would be difficult to gauge. Having determined the spectral types of the stars, astronomers can watch the part-





BETELGEUSE, a brilliant red supergiant, is a variable star that marks the upper right shoulder of Orion the Hunter. It may become a supernova one day in the cosmic near-future. LEE C. COOMBS

THE PLEIADES STAR CLUSTER stands out in this spectrum of its brightest stars. Such a spectrum reveals much about the nature of the cluster's stars. Chris Schur created this shot with a 400mm lens at f/6.3, 3M1000 film, and a 22-minute exposure using a 30° prism. CHRIS SCHUR

ONE OF THE PRETTIEST DOUBLE STARS of the springtime sky, Zuben el Genubi (Alpha Librae) can be "separated" into two stars in binoculars, the primary and secondary removed by nearly 4'. JOHN CHUMACK

ners orbit each other and learn about the masses, distances, ages, and other information that adds to the knowledge bank about how stars form and evolve. Such systems offer a convenient laboratory for orbital mechanics that would not exist from observations of single stars or the Sun alone. Some binary systems offer the best evidence for the existence of exotic phenomena like black holes. It's impossible to see a black hole, but astronomers can see the effects such an object has on the other star in the binary system.

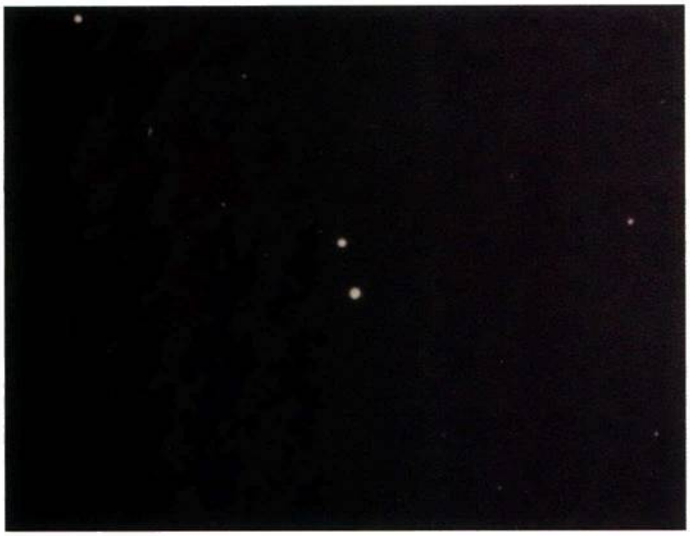
splitting binaries with telescopes

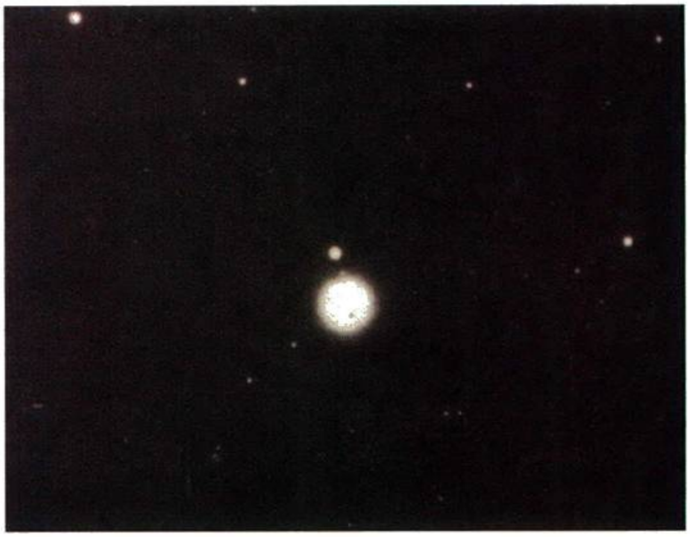
Backyard observers enjoy viewing double and multiple stars because of the pretty colors they sometimes display and the challenge of "splitting" the components. Hundreds of double stars are visible in even a 2-inch telescope, so they provide a nearly inexhaustible source of observing targets. And because they are bright points of light, many double and multiple stars can be observed from relatively light-polluted areas with little problem.

Perhaps the most popular double star is Mizar (Zeta Ursae Majoris), the brighter of the pair of stars which make up the middle "star" in the handle of the Big Dipper. Along with the other star, named Alcor, Mizar makes a famous optical double. Mizar's magnitude 2.4 and 4.0 white components are separated by a generous 14.4". Another great double is Albireo (Beta Cygni), the star marking the beak of the summertime swan Cygnus. It consists of a yellow 3rd-magnitude primary star and a blue 5th-magnitude companion, separated by 34.3", an actual distance of 400 billion miles. Eta Cassiopeia is a fine double for small telescopes, consisting of magnitude 3.5 and 7.2 stars separated by 14" with colors yellow and pale red, respectively.

variable stars

The Sun seems like a reliable companion in our lives, constant in every way. Yet it varies ever so slightly in energy output. Other stars, however, vary wildly in their light output for a variety of reasons. Astronomers classify these stars into a bewildering array of categories collectively called variable stars. Intrinsic variable stars change their light output due to variations in the star itself; other types of variables fluctuate in brightness for external reasons. The most straightforward class of intrinsic variable is the pulsating variable, which varies due to physical expansion and contraction of the star. Like a swinging pendulum, pulsating variables bloat in size and then rebound by gravitational attraction. Cepheid variable stars, named for the prototype Delta Cephei, show a definite rela-





tion between period and luminosity. Thus, they can be used as "standard candles" by astronomers who want to determine distances to objects that contain them.

Variables may have long or short periods of light fluctuation. RR Lyrae stars are short-period variables that fluctuate in brightness over intervals of less than one day. Long-period variables are aged, red stars like their prototype Mira (Omicron Ceti), that swing up and down in energy with periods as long as several years. Eruptive variables and flare stars produce erratic surges in brightness. Eclipsing binaries drop and rise in brightness because one member of a double star system temporarily blocks the other. They are not intrinsic variables. *Novae,* the Latin word for "new," are stars in late stages of evolution that erupt dramatically in brightness. Supernovae, the most cataclysmic events in the universe, are high mass stars that run out of fuel to burn and then explode, scattering debris throughout space. Supernovae can, for days, or even weeks, outshine an entire galaxy.

MIRA, "THE WONDERFUL," is the ▲ prototypical long-period variable star. Located in Cetus the Whale, at minimum (top left) the star glows dimly at magnitude 9, while at maximum (top right) it nearly reaches 3rd magnitude.

LOWELL OBSERVATORY

THE BRIGHTEST STAR IN THE SKY, ◀ Sirius in Canis Major is in reality 23 times brighter than the Sun, has 2.4 times its mass, and is nearly twice as large. It lies at a distance of 8.7 light-years.

RON MIKKELSON

MULTITUDINOUS COLORS circle ▶ the sky as stars trail over a reed boat in this spectacular shot by amateur astronomer Fred Espenak.

FRED ESPENAK

the young and the aged: a look at star clusters

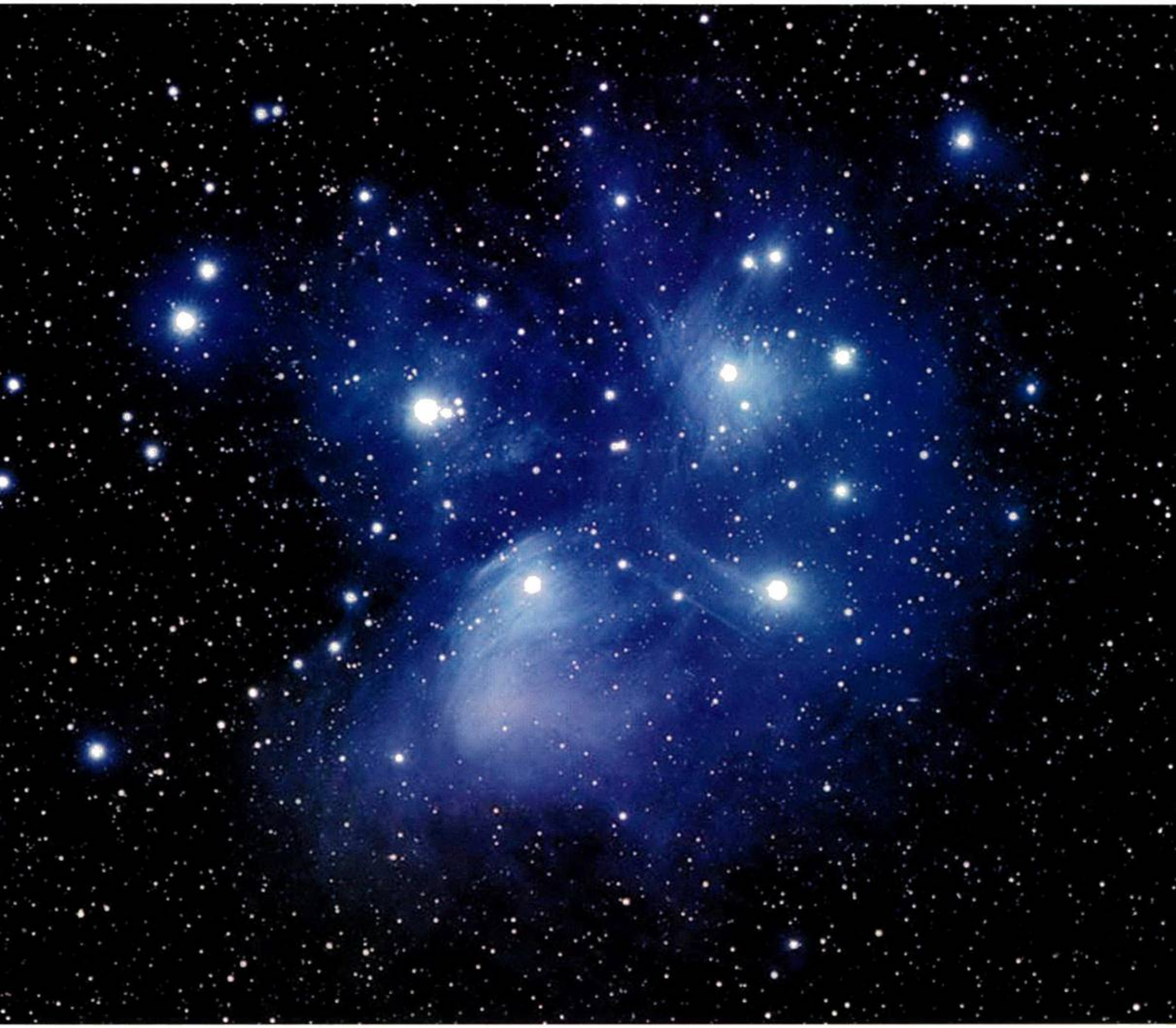
If you venture outside on a night when the Milky Way is visible, you'll notice that the stars in that glowing band of light are not uniformly distributed. Instead, you'll see areas of greater and lesser concentration — places where stars seem to clump together in groups separated by star-poor regions. Part of this clumpiness is due to a perspective effect, but for the most part the clumpiness is real. Stars and interstellar matter are not distributed evenly throughout the galaxy. This is due to a variety of factors including the rotation of the galaxy and the strong tug of gravity, but it underscores an important point about stars. They are not formed in isolation, but instead, they are created together in star clusters.

Stars form from recycled hydrogen gas and dust that coalesce into a cloud. This process may take millions of years. In our galaxy alone, thousands of these clouds exist. Eventually, as stars begin to form, the cloud becomes an emission nebula, in effect, an interstellar nursery. Our Sun, for example, was not always a lone star but formed in a group within a nebulous cloud. If this is so, why don't all stars exist in clusters? Because gravitational interactions among stars in a cluster, acting over periods of millions of years, slowly break apart star clusters and disperse their members throughout the spiral arms of the galaxy. This is the scenario for the first of two major types of star clusters. The second type is a very different animal.

open star clusters

Loose, irregularly shaped star clusters visible in the plane of the Milky Way are called open star clusters, or sometimes, galactic star clusters. These objects consist of young stars recently formed from a nebulous cloud of gas and dust — in many cases, in fact, nebulosity not yet formed into stars is visible in association with the stars in the cluster. Open clusters exist in the disk portion of the galaxy and provide the means for the birth and early years of a huge percentage of stars. They generally contain a few hundred to a few thousand members but can contain only a few dozen. They generally measure a few light-years across at most. All known open clusters are relatively close to the Sun — 10,000 light-years or less — because at greater distances open clusters merge into the rich background of individual Milky Way stars. Such clusters are important to astronomers because they formed at a given time in the

OPEN CLUSTER M11, in the constellation Scutum, packs hundreds of stars into about 20 light-years of space. This color composite was created from CCD images taken at the Burrell Schmidt Telescope, located on Kitt Peak in southwestern Arizona. N. A. SHARP, REU PROGRAM/NOAO/AURA/NSF

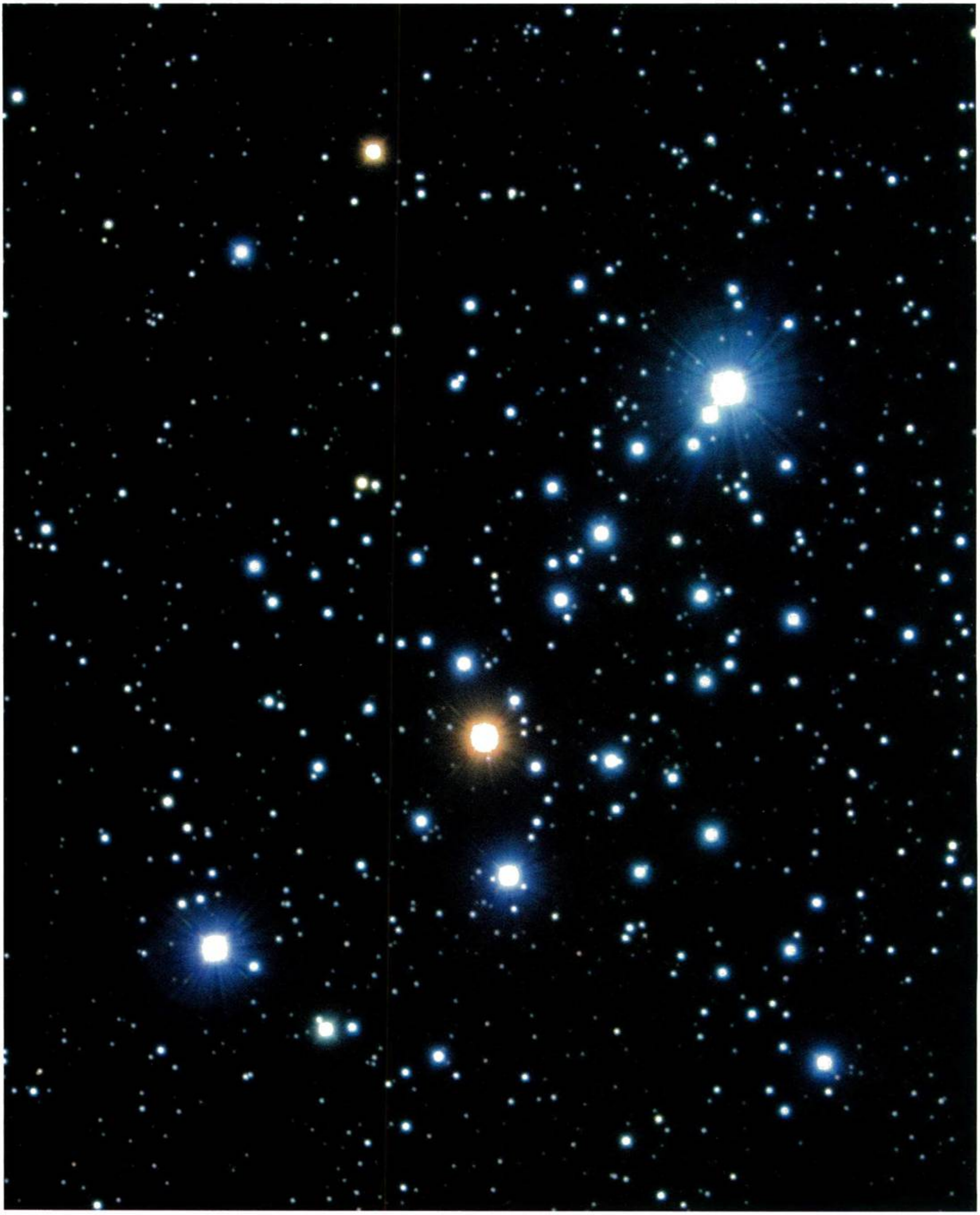


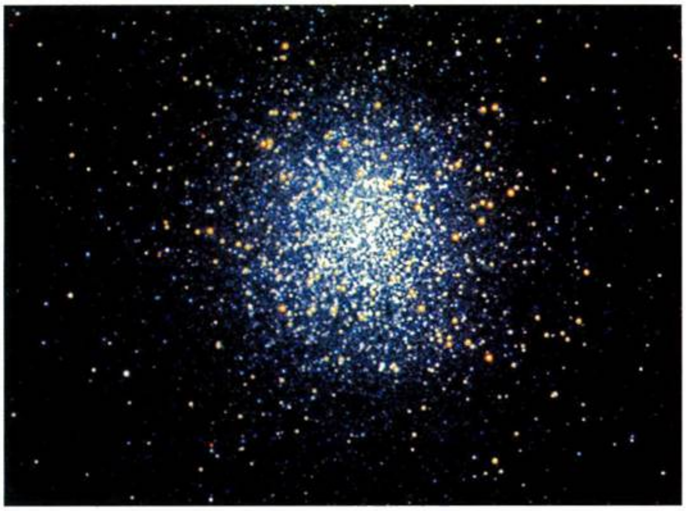
history of the galaxy and therefore allow a sampling of the chemical and astrophysical conditions present during the cluster's birth. The only significant variable in a star cluster is the range of different masses for the various stars, and this is an important point for astronomers wishing to gain insight on how stars burn their fuel and otherwise behave throughout their lives.

hunting open clusters with binoculars

Because open star clusters lie relatively close to us in galactic terms, many consist of bright stars. A few dozen such clusters are beautiful objects not only in telescopes but also in binoculars, and several stunning examples can be seen with the eye alone under a dark sky. One of the most impressive such clusters is the Pleiades (M45) in Taurus, a small, dipper-shaped group of bright stars also called the Seven Sisters. On any dark winter night the Pleiades is visible to the naked eye as a tiny cloud of misty light. Look carefully and you'll see five or six tiny stars within the patch of light. Few people see seven stars with the eye alone — a test of keen eyesight. In binoculars, however, the Pleiades comes alive with dozens of gleam-

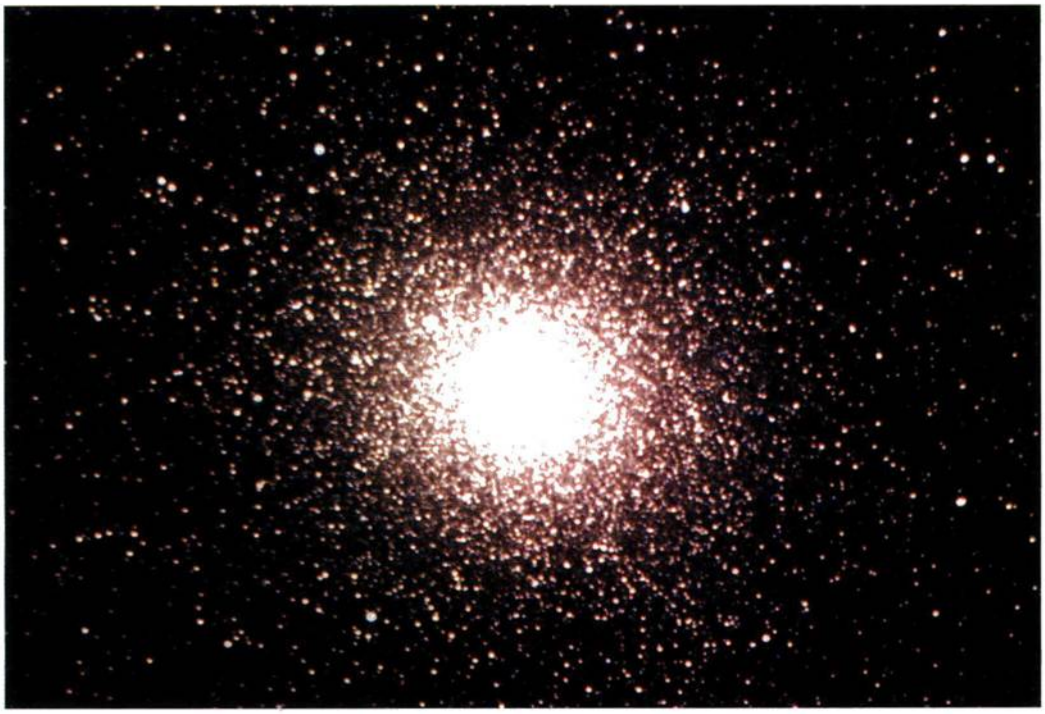
THE PLEIADES, M45, radiates blue in this Tony and Daphne Hallas image. The California skyshooters used a 7-inch refractor and four 6x7 negatives to produce the substantial nebular detail visible in the photo. TONY AND DAPHNE HALLAS





BLUE AND GOLD SPECKLES ▼ make up M13, the Hercules Cluster, photographed by Tony and Daphne Hallas. The Hallases used a 14.5-inch f/8 Cassegrain for this deep exposure of the cluster. TONY AND DAPHNE HALLAS

GLOBULAR CLUSTER M80 gains ▲ significance from the fact that it was one of Charles Messier's original discoveries. Messier found this globular within the constellation Scorpius on January 4, 1780. M80 is one of the densest clusters in the Milky Way. HUBBLE HERITAGE TEAM (AURA/STScI/NASA)



OMEGA CENTAURI, the ◄ brightest globular cluster in the sky, is a huge object located in the constellation Centaurus. Jason Ware used a 16-inch SCT to capture this stunning image of more than a million suns. JASON WARE

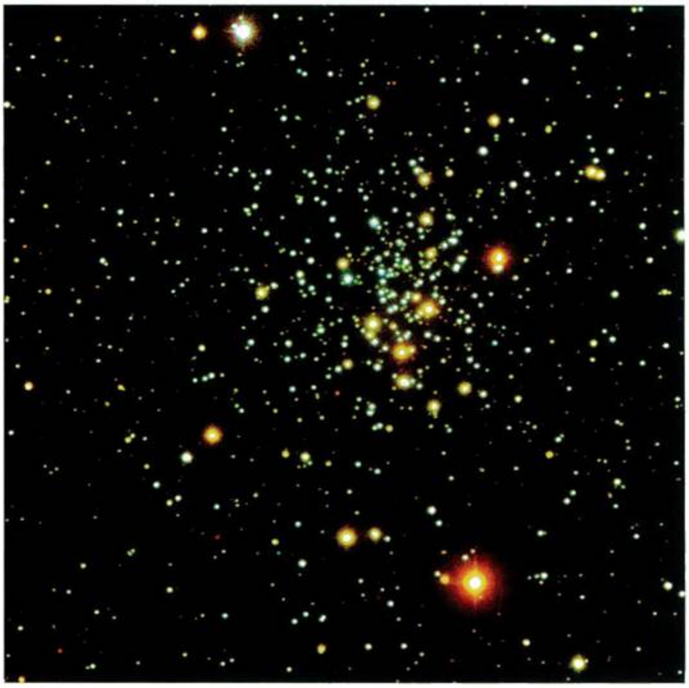
ing blue and blue-white stars, many arranged in tight little geometric patterns. In a telescope, it's possible to glimpse a small wisp of reflection nebulosity, dust associated with and illuminated by the young stars. The cluster is about 2° across — four times the size of the Moon — and lies at a distance of 380 light-years. Altogether the group shines with the light of a single 1st-magnitude star.

IRREGULAR M103 lies in the ◄ constellation Cassiopeia; astronomers estimate its age at "only" 20 million years. This true-color image was created from combining 15 frames taken in the BVR passbands at the Kitt Peak National Observatory's 2.1-meter telescope. HILLARY MATHIS, N. A. SHARP/NOAO/AURA/NSF

Other impressive open clusters for binoculars include the Hyades — located just south of the Pleiades, the great Coma Berenices star cluster (Melotte 111), the famed double cluster in Perseus, the Beehive Cluster (M44) in Cancer, Southern Hemisphere wonders IC 2602 and NGC 3532, both in Carina, and a slew of clusters in the summer Milky Way that includes M6, M7, and NGC 6231 in Scorpius and M39 in Cygnus. Hundreds of fainter clusters are visible in small telescopes, but you may find that you enjoy viewing bright star groups most in binoculars, whose wide field of view enables you to include the entire cluster without moving around.

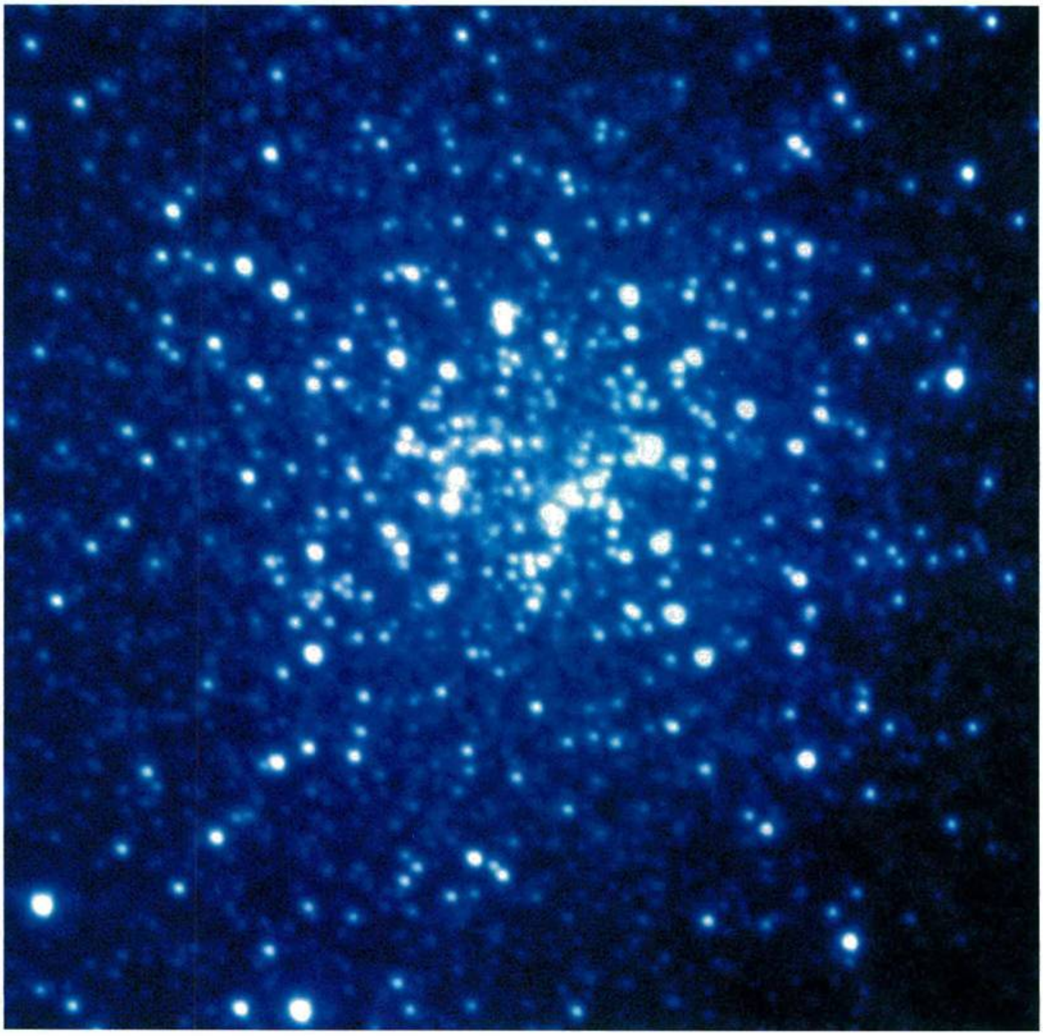
globular star clusters

The other type of star cluster is called a globular star cluster.

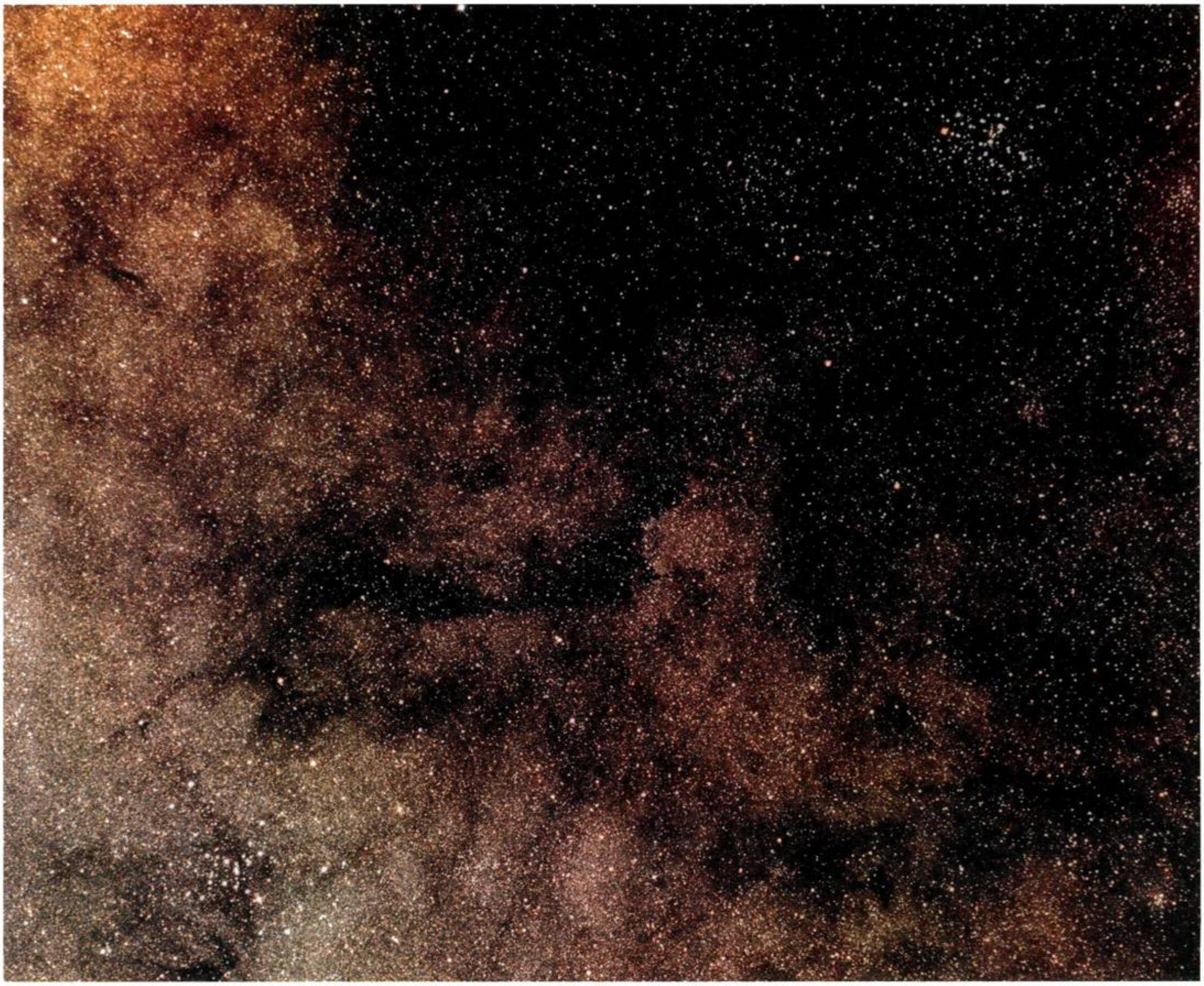


LOCATED IN SAGITTARIUS, globular cluster M70 has a brilliant core that contributes to its brightness. This composite was created from images taken at the Kitt Peak National Observatory. ▲ REU PROGRAM/NOAO/AURA/NSF

SIMPLE IN APPEARANCE, star cluster NGC 2420 in Gemini may contain many clues into the complex history and evolution of the Milky Way Galaxy. ◥ WIYN/NOAO/NSF



NGC 6934 CONTAINS SO MANY STARS that even the thin atmosphere above the Gemini North Telescope on Mauna Kea blurs the blue starlight enough that the stars overlap. ► GEMINI OBSERVATORY, UNITED STATES NATIONAL SCIENCE FOUNDATION, AND THE UNIVERSITY OF HAWAII INSTITUTE FOR ASTRONOMY



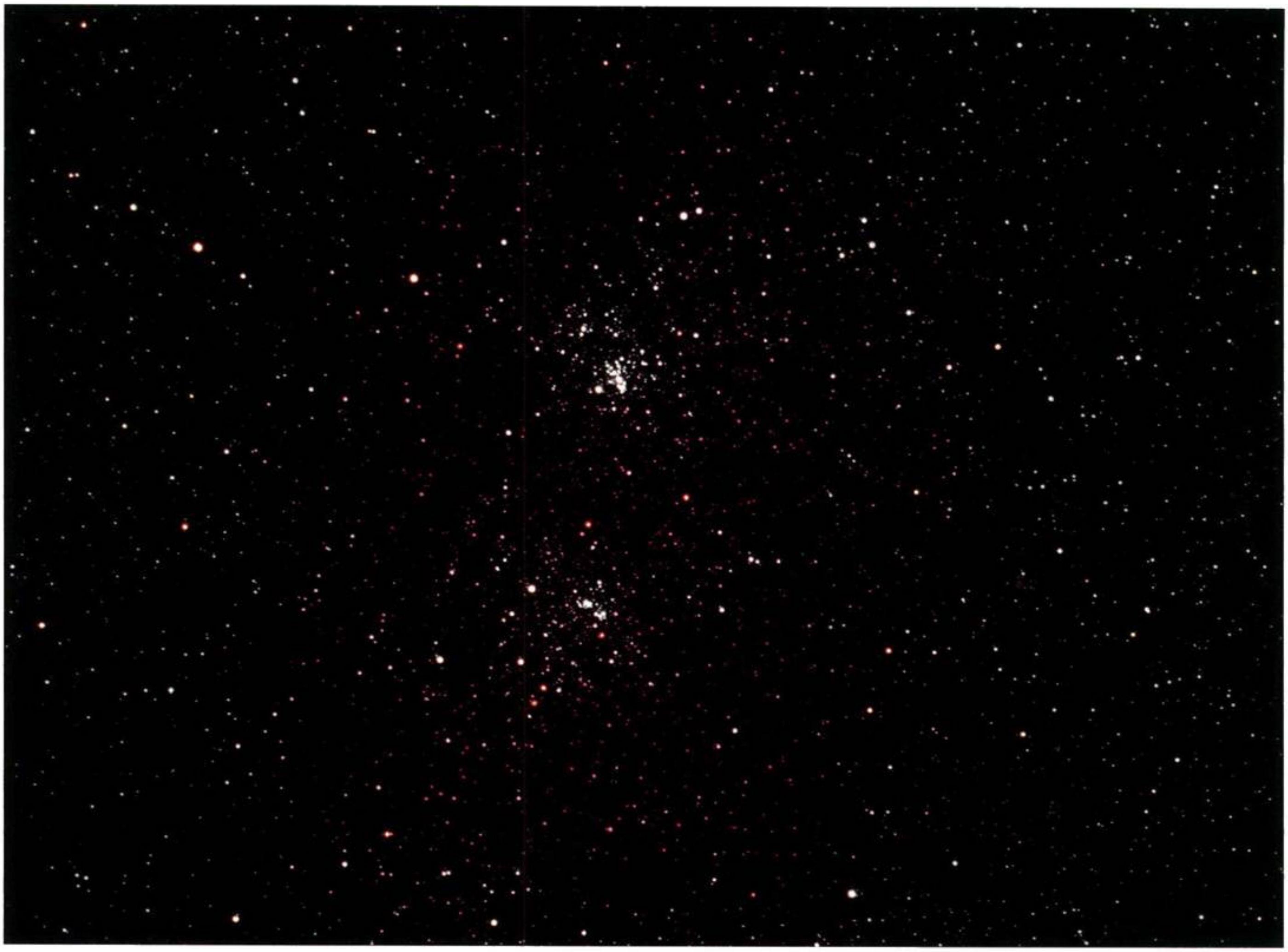
BURIED IN THE MILKY WAY, M6 (top right) and M7 (bottom left) in Scorpius require a wide-field to appreciate as star clusters. Jason Ware shot this image with a 12-inch f/2.2 Meade Schmidt camera, Fuji 400 film, and a composite of two 7-minute exposures. JASON WARE

Globular clusters are both astrophysically and observationally completely different from open clusters. They are giant spheres of stars many times larger than the biggest open clusters, lying outside the galaxy's disk in a barren region called the galactic halo. They are old, predominantly yellow suns that formed long ago as the galaxy settled into its present shape. Globular clusters are among the oldest relatively unchanged entities in the universe, and as such they provide astronomers with a time capsule with which to look backward to the galaxy's early history. About 300 such objects are known in the Milky Way, most lying from 10,000 to 200,000 light-years away, spanning 20 to 300 light-years across, and containing between 30,000 and 2 million stars.

Globular star clusters slowly orbit the center of the galaxy in long, elliptical paths. Most of the time they are quiescent, far away from any of the action that permeates the galaxy's disk. But every few tens of millions of years a globular cluster may pass down through the plane of the galaxy and be swept clean of dust and gas that lies within it. Thus, globular clusters are essentially sterile, emptied of material, spheres containing only aged stars.

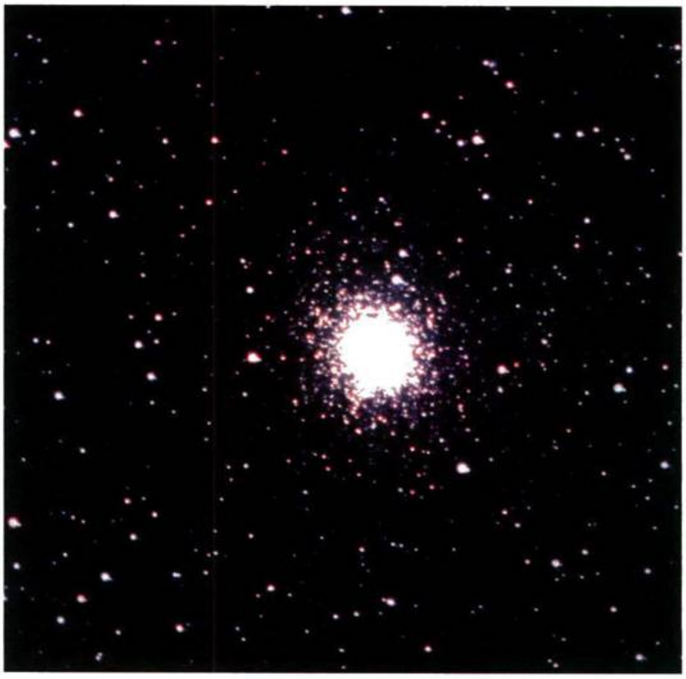
resolving the globes: summertime spectacle

Globular clusters are a joy to observe, and although at first glance many appear to be similar in photographs, they are actually quite varied when viewed with telescopes. Because they are distributed around the galactic center, most globular clusters appear to be concentrated in the summer sky (Sagittarius, the group of stars that marks the position of the galactic center, is a summer constellation). Because of this, there are few more enjoyable summertime observing events than hauling out your telescope and locating and viewing globular clusters.



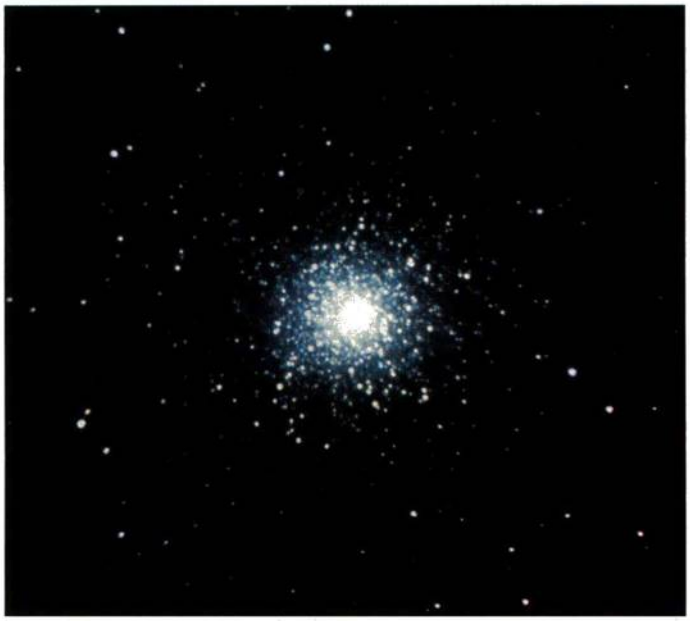
THE DOUBLE CLUSTER IN PERSEUS, NGC 869 and NGC 884, ▲ constitutes one of the brightest deep-sky objects in the heavens. Mark E. Killion made this image with a 5-inch Takahashi refractor at f/5.9, Fuji Super G 400 film, and a 35-minute exposure. MARK E. KILLIO

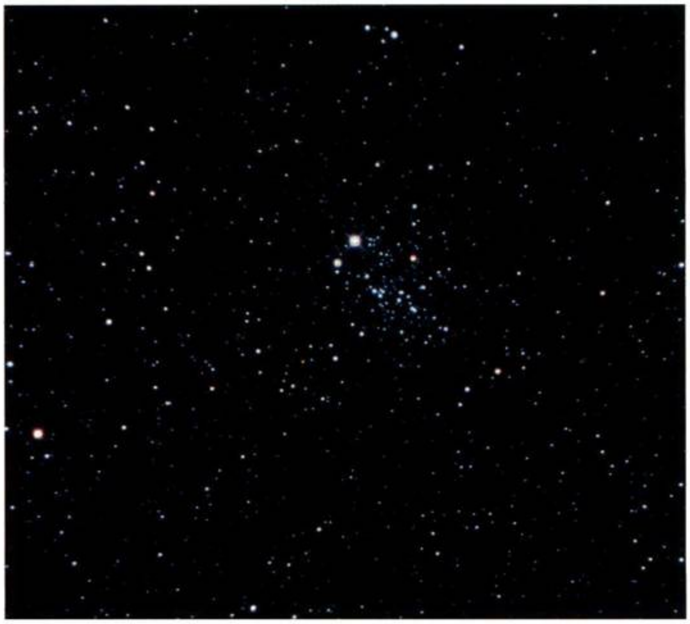
THE GREAT GLOBULAR CLUSTER 47 TUCANAE, ► one of the best in the sky, lies in a far-southern constellation that makes it inaccessible to Northern Hemisphere observers. FRED ESPENAK

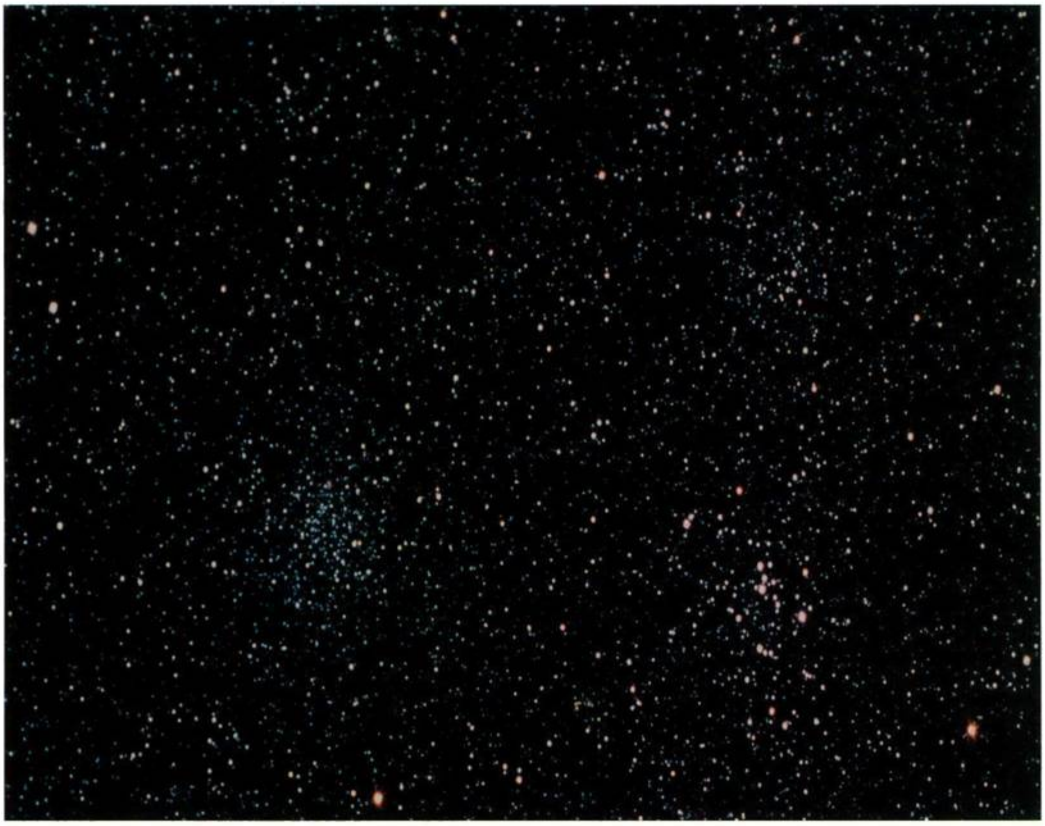


Several bright globulars are visible — barely — to the naked eye. These include Omega Centauri (NGC 5139), the Hercules Cluster (M13), and clusters M4 in Scorpius and M22 in Sagittarius. But to see most globulars, even as fuzzy, bloated "stars," you need at least binoculars. Furthermore, to resolve most globular clusters into their constituent stars, you'll need at least a 4-inch telescope, but the bigger your scope, the better.

The brightest globular cluster in the sky is Omega Centauri, visible as a 4th-magnitude "star" in the southern constellation Centaurus. Larger than the disk of the Moon, this hazy ball contains more than a million stars and is bright in our sky because it lies relatively close to the Sun. In a 6-inch telescope Omega Centauri







THE OWL CLUSTER in ▲
Cassiopeia, NGC 457, huddles its members around the orange sun Phi Cassiopeiae. Lee C. Coombs used a 10-inch f/5 reflector, Ektachrome P200 film, and a 22-minute exposure for this shot. LEE C. COOMBS

THE HERCULES CLUSTER, M13, ▼ is generally regarded as the most celebrated globular cluster in the northern sky. Bill Iburg recorded this image with a 14-inch SCT at f/5.5, Ektachrome 200 film, and a 30-minute exposure using a cold camera. BILL IBURG

PAIRED ONLY BY COINCIDENCE, ◄ open clusters M46 (left) and M47 in Puppis make a low-power field glisten with stars. M46 contains a tiny, reddish planetary nebula dubbed NGC 2438. JOHN CHUMACK

appears as a huge hazy glow peppered with hundreds of tiny, white and yellow stars across an area spanning 30'. It is an amazing sight not easily forgotten.

The favorite globular cluster for Northern Hemisphere observers is the Hercules Cluster. Lying within the "keystone" asterism of Hercules, this 6th-magnitude object measures about half the diameter of Omega and contains a much more condensed, ball-like center. A 6-inch scope shows bright lanes of stars winding away from the center of this cluster, producing a vivid, three-dimensional effect. Other impressive globulars include M15 in Pegasus, M3 in Canes Venatici, 47 Tucanae in the deep southern sky, M5 in Serpens, and M55 in Sagittarius.

cosmic clouds: bright and dark nebulae

On a dark summer night one of the most awe-inspiring sights in the natural world arches overhead, sparkling and glistening like diamond dust on black velvet. Simply step outside on such a night and you'll see the Milky Way, the smooth, fuzzy glow of the disk of our galaxy seen from within. It stretches from Scorpius and Sagittarius in the south, to Cygnus high overhead, to Cassiopeia in the north. Most of this glow comes from the unresolved light of countless thousands of stars. But scattered throughout the stars are thousands of nebulae — clouds of gas and dust — that litter the disk component of the Milky Way and play critical roles in the ways stars are born and die.

The primary constituent of these clouds is hydrogen, the most abundant element in the universe. Quantitatively, hydrogen plays a crucial role in everything that exists in the Milky Way and beyond, including being a primary component of water, the life-giving fluid so precious to life on Earth. Hydrogen and other elements compose these interstellar clouds, and the exact way they are composed, the way forces act on them, and where they exist in the galaxy combine to characterize nebulae in very different ways.

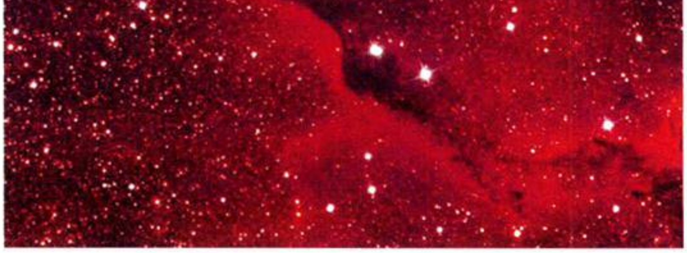
emission nebulae

Astronomers call the brightest and most easily observed interstellar clouds emission nebulae. These regions of gas glow like a soft light bulb by fluorescence because their atoms are excited into ionization by nearby hot stars. Many emission nebulae are interstellar birthplaces, regions where ancient gas from dead stars has gravitationally collapsed to a point where new stars form from the recycled elements. When hot, young stars within an emission nebula throw off immense amounts of energy, the surrounding gas cloud lights up and is visible in telescopes thousands of light-years away.

Other types of emission nebulae are included together with star-forming regions as a class because they glow in the same way, from radiation supplied by hot stars. Yet supernova remnants and planetary nebulae are very different animals from star-forming regions. Supernova remnants are the quickly expanding gaseous remains of massive stars that ended their lives in violent explosions after depleting their nuclear fuel. Planetary nebulae are the slowly expanding gaseous remnants of less massive stars that ended their existence by "belching" off layers of material after consuming their last stockpiles of nuclear fuel. Superb examples of all three types of emission nebulae are visible in backyard telescopes.

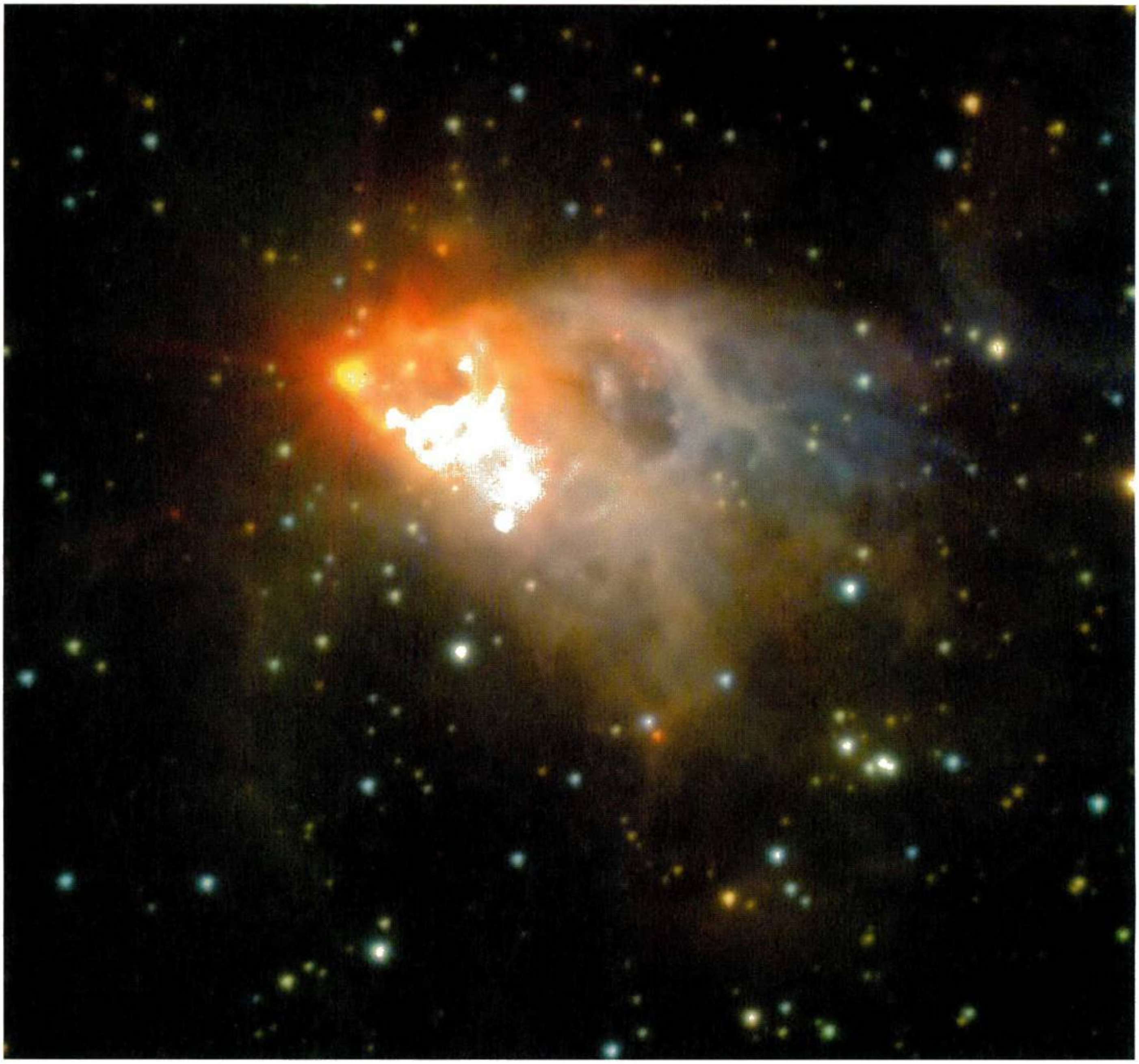
from Orion to invisibility

The brightest emission nebulae are visible to the naked eye. Such is the case with the Orion Nebula (M42), the most famous of all emission regions, visible as a soft glow in the sword of Orion. This object is one of the largest emission nebulae known in our galaxy, and is conveniently located only about 1,500 light-years away. Binoculars show that M42 is a nebular cloud peppered with a few bright stars lying inside it. A 4-inch telescope at moderate power shows distinct features in M42, such as the high surface brightness central core, the multiple star Theta^1 Orionis, double star Theta^2 Orionis, a dark protuberance called the Fish's Mouth in the bright core, and a faint halo of nebulosity fanning away from the center. In total extent the Orion Nebula covers an area 85' by 60', larger than the Full Moon, but only about half that area is visible through backyard telescopes because of the faintness of the outlying parts of the nebula.



THE DARK NEBULA VAN DEN BERG 142 in Cepheus is a challenging object for visual observers. Tony and Daphne Hallas captured this image using a 14.5-inch f/8 Cassegrain and Fuji HQ100 hypered film, exposing for 90 minutes.

TONY AND DAPHNE HALLAS



A DRAMATIC INFRARED IMAGE offers a fresh look into the early stages of giant star formation in our galaxy. The image colorfully displays a nebula of gas and dust expelled from the star AFGL 2591.

GEMINI OBSERVATORY/COLIN ASPIN

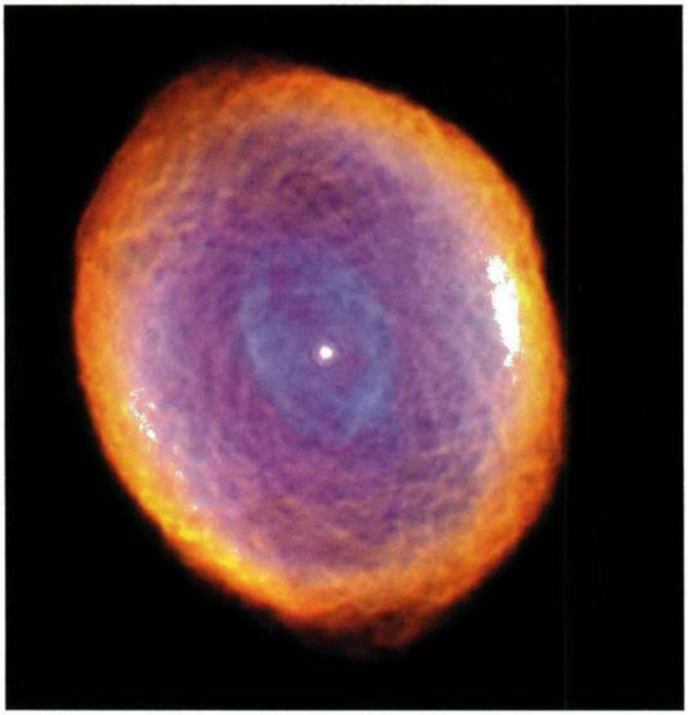
Other large, bright, and relatively close emission nebulae are visible to the naked eye under dark skies. These include the Eta Carinae Nebula (NGC 3372) — a magnificent object deep in the southern sky — the North America Nebula (NGC 7000) in Cygnus, IC 1396 in Cepheus, the Lagoon (M8) and Trifid (M20) nebulae in Sagittarius, the Eagle Nebula (M16) in Serpens, the Omega Nebula (M17) in Sagittarius, and the Tarantula Nebula (NGC 2070) in Dorado, far to the south. Such emission nebulae aptly demonstrate the difference in sensitivity between photography and the human eye: Although most look vivid red in long exposure photos, you'll see them in a telescope as gray-green. Unfortunately, eyes are not as sensitive to the same wavelengths of light as is film.

A handful of supernova remnants are visible in backyard telescopes. The reason for the relative rarity of these objects is simple. Over the span of several thousand years, for example, relatively few stars become supernovae in any single galaxy like the Milky Way. When a star does "go supernova," it produces a bright ring of gas that glows brightly and then slowly dims as it expands into the interstellar medium. Astronomers have calculated that the typical supernova remnant has a lifetime of only some 20,000 to 50,000 years. So in order to see a supernova remnant as a reasonably bright object it must be relatively close in the galaxy and must be less than 50,000 years old.

For small telescopes, the best example of a supernova remnant is the Crab Nebula (M1) in Taurus. This little oval nebulosity glows at about 9th magnitude and

THE HORSEHEAD NEBULA, B33, presents one of the great challenges for visual observers. An elusive resident of the constellation Orion, it is small and very faint in an eyepiece, but beautiful and well-defined in photos. NASA, NOAO, ESA AND THE HUBBLE HERITAGE TEAM (STScI/AURA)

REFLECTION NEBULA NGC 1999 appears similar to a cloud passing in front of the Sun. Light from an embedded source illuminates its particle-sized dust to create a reflection nebula. NASA AND THE HUBBLE HERITAGE TEAM (STScI/AURA)



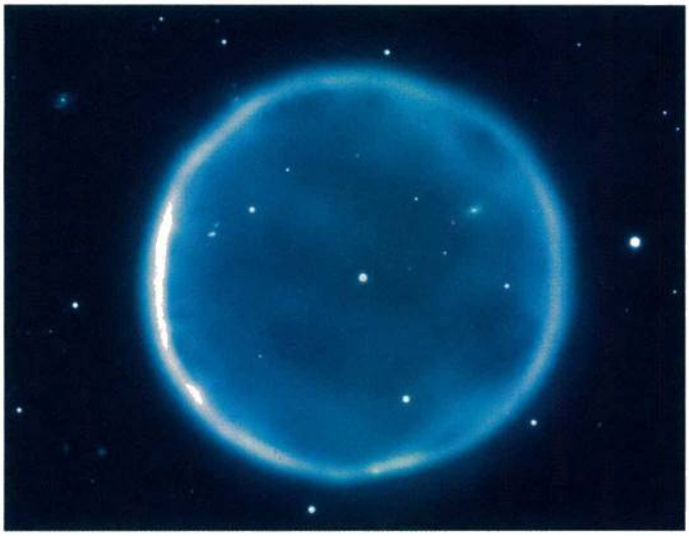
A GLIMPSE OF OUR SUN'S FUTURE, the planetary nebula IC 418 lies about 2,000 light-years from Earth. Once a red giant, the star ejected its outer layers into space to form the nebula. The bright stellar remnant in the center is the hot core of the red giant. Ultraviolet radiation pours into the surrounding cloud of gas, illuminating it. NASA AND THE HUBBLE HERITAGE TEAM (STScI/AURA)

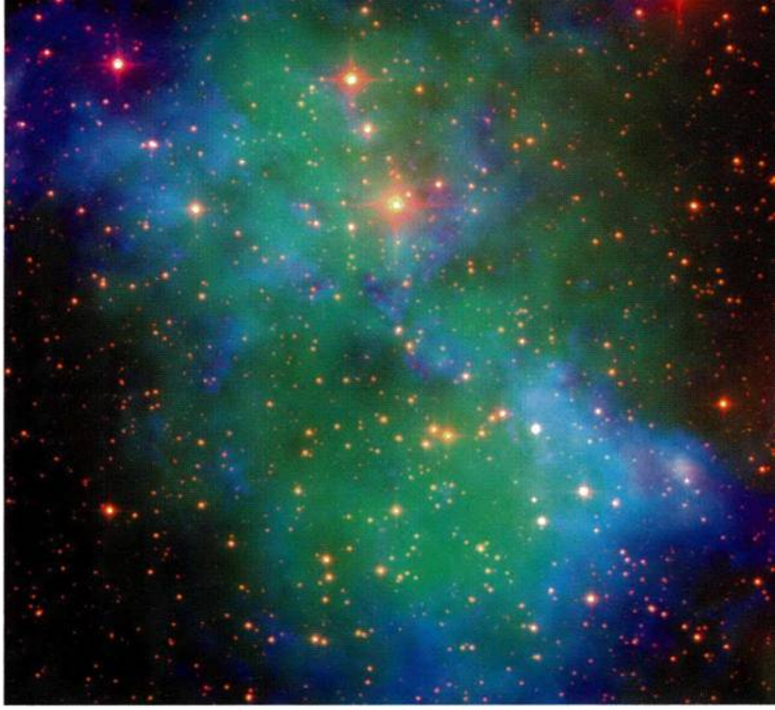
so is relatively easy to see in a 4-inch telescope. Curiously, Chinese and Native American records describe the presence of a bright daytime star in the constellation Taurus that remained visible for several weeks in the year 1054. Indeed, this star became the supernova that produced the Crab Nebula and we are today, more than 900 years later, able to see the remains of this stellar explosion. Close-up photos of the Crab Nebula show thin tendrils of gas speeding out ahead of the cloud as it expands, and early large telescope observations of these tendrils produced the common name "Crab" Nebula. These features are difficult to see with anything but the largest backyard telescopes, however. Other notable supernova remnants for amateur scopes include the Veil Nebula (NGC 6960, NGC 6992–5) and the low-surface-brightness object NGC 6888, both in Cygnus.

dumbbells and donuts

Because most are small and have relatively high surface brightness, planetary nebulae are much easier to observe than supernova remnants. The name planetary nebula derives from the famous 18th century observer William Herschel, who likened the telescopic appearances of these objects to the disks of planets. Although most planetaries appear as disks, they are actually spheres of gas and their uneven growth causes in some examples far more peculiar shapes than mere disks. The prototypical planetary is the Ring Nebula (M57) in Lyra, an object measuring slightly over 1' across and possessing a dark center, such that it appears to be a ghostly smoke ring, or glowing donut.

The Dumbbell Nebula (M27) in Vulpecula is larger and brighter than the Ring. Given the inglorious name because its shape actually resembles a dumbbell, M27 is visible in binoculars as a fuzzy glow. Telescopes are required to



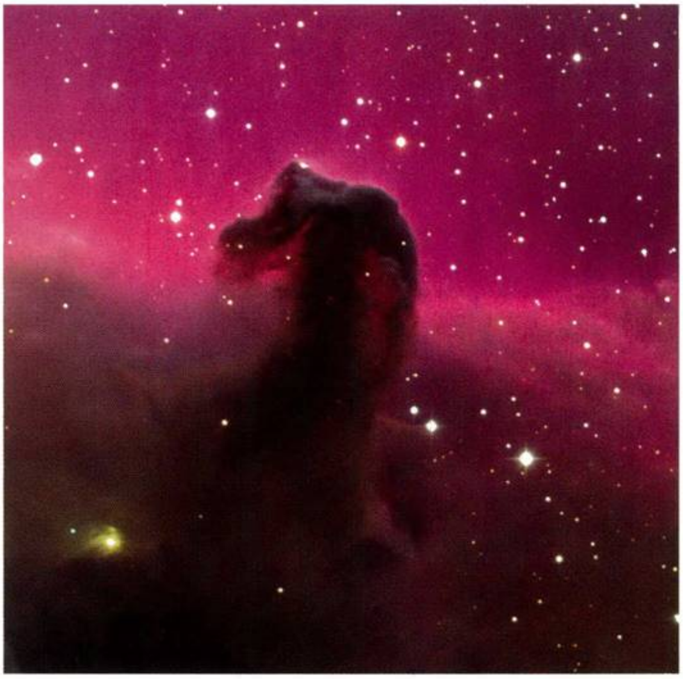


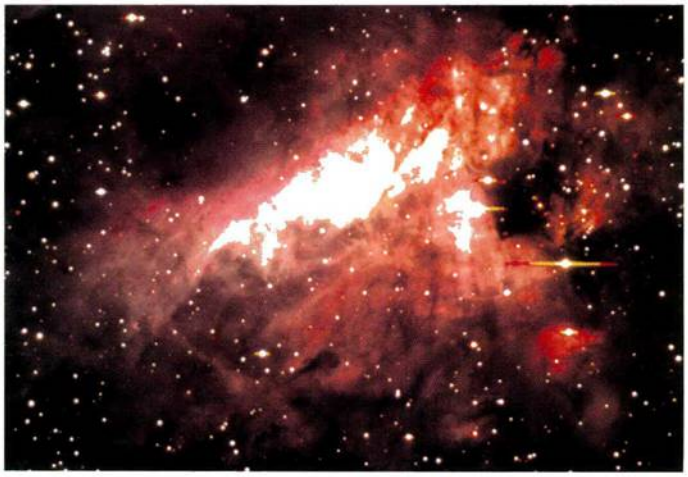
show the shape distinctly, however, and a good 6-inch scope shows not only the dumbbell (or butterfly) shape but also fainter "ears" of nebulosity that nearly close the object into an illuminated oval. A good 8-inch telescope shows several stars splattered across the face of this nebula, the one in the center of the object — a dim, 13th-magnitude orb — being the progenitor star. The Dumbbell measures 8' by 6' in extent, quite large for a planetary nebula.

The Dumbbell is not the largest, brightest, or closest planetary nebula, however. That honor belongs to the Helical Nebula (NGC 7293) in Aquarius. Measuring 15' by 12', half the size of the Full Moon, the Helix is large enough to see easily in binoculars, but only from a dark sky. The nebula's total magnitude is 6.5, but it suffers from low surface brightness — its light is so spread out that little pieces of the nebula appear relatively dim. Hence, a wide-field telescope at low power is the best instrument for viewing the object. The Helical Nebula's southern declination places it low in the sky for many Northern Hemisphere viewers. Nevertheless, it is visible on dark, moonless nights.

reflection nebulae

Emission nebulae are not the only type of interstellar gas cloud.





THE DUMBBELL NEBULA, M27, ▲ shows up beautifully in this false-color image made with the WIYN telescope. The stunning myriad of colors results from the use of narrow-band filters. NIGEL SHARP, RICH REED, DAVE DRYDEN, DAVE MILLS, DOUG WILLIAMS, CHARLES CORSON, ROGER LYNDS, AND ARJUN DEY/NOAO/WIYN/NSF

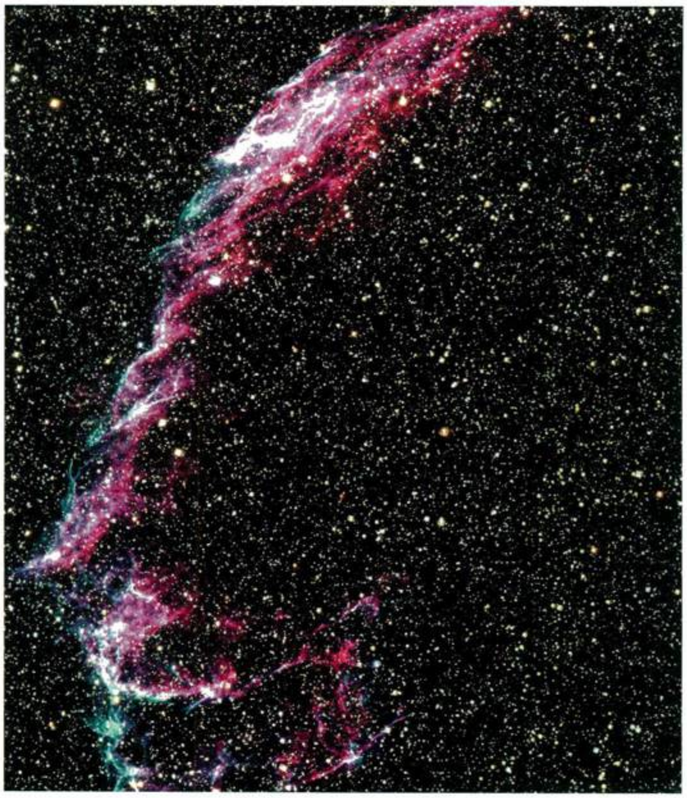
PLANETARY NEBULA ABELL 39 ▼ appears as a glowing, transparent ball in this NOAO image. The WIYN telescope at Kitt Peak National Observatory was used for this image along with a blue-green filter to isolate the light emitted by oxygen atoms. The nebula lies about 7,000 light-years from Earth in the constellation Hercules. WIYN/NOAO/NSF

THE HORSEHEAD NEBULA, ◄ lassoed here by the 0.9-m telescope of the Kitt Peak National Observatory, was first recorded in 1888 on a photographic plate taken at the Harvard College Observatory. This true-color image combines five frames with a blue filter, three frames with a green filter, and two frames with a red filter for a combined total of 47 minutes. NIGEL SHARP/NOAO

THE OMEGA NEBULA, M17, ◄ reveals its true colors in this 1993 image. Also known as the Swan Nebula, this object is one of the brightest in the summer Milky Way. TODD BOROSON/NOAO/AURA/NSF

THE PELICAN NEBULA resides in ▲ the constellation Cygnus. A challenge for visual observers, it is one of the loveliest nebulae for astrophotographers to capture on film. This false-color composite image shows an ionized front of gas along the nebula's edge.
JOHN BALLY (UNIVERSITY OF COLORADO), NOAO/AURA/NSF

THE BREATHTAKING ROSETTE ◀ **NEBULA** abounds with ultraviolet light from young, hot, blue stars. A cycle of star formation is erupting throughout the energetic cloud of gas. T. A. RECTOR, B. A. WOLPA, M. HANNA, NOAO/AURA/NSF



THE VEIL NEBULA in Cygnus is ▶ a favorite supernova remnant for amateur observers. The exploded remains of a massive star, the gas will slowly spread into the interstellar medium and enrich new stars with heavy elements.
N. A. SHARP, REU PROGRAM, NOAO/AURA/NSF

Reflection nebulae are lower energy clouds that have not been excited into luminescence. Rather, they are regions visible only because they reflect light from nearby stars. That a nebula is visible over hundreds of light-years simply by bouncing light from a nearby star is incredible, and as you might expect, reflection nebulae are much fainter than emission nebulae. The visibility of any nebula — and especially reflection objects — is controlled by the local geometry of the object and its position relative to neighboring stars.

Reflection nebulae are challenging observing targets and only a handful are bright enough to be easily viewed with small telescopes. One of the best is M78, a small gas cloud surrounding a pair of bright stars in central Orion, not far north of Orion's belt. Reflection nebulae have low surface brightness and M78 is no exception, so use a relatively wide-field eyepiece to find and observe M78. You'll see it as a faint glow surrounding the stars.

Substantially more challenging than M78 is the Merope Nebula (NGC 1435), an extremely faint patch of reflection nebulosity surrounding one of the brightest stars in the Pleiades (M45) star cluster in Taurus. The Merope Nebula is faint enough to require that you use a moderate size (8-inch or larger) telescope, averted vision, and that you place the star just outside of a high-power field to eliminate glare from the star. On nights of superb sky steadiness you may catch a glimpse of this deep-sky observing challenge.

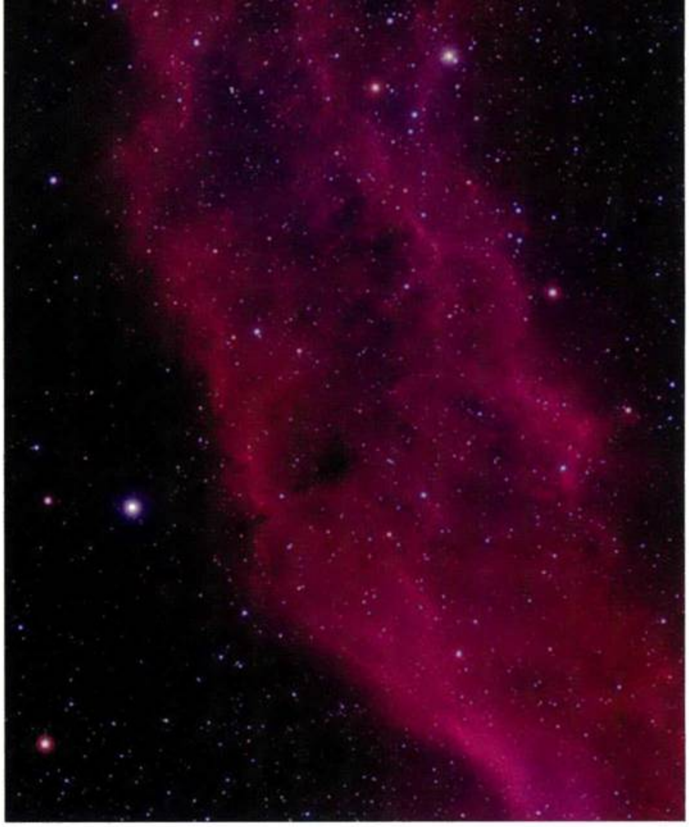
dark nebulae

A third type of interstellar cloud is the hardest type to recognize. Dark nebulae are clouds of extremely fine dust particles not visible at all directly. To detect a dark nebula astronomers must see a lack of something else they know lies beyond it. For example, dark nebulae are most easily detected in the rich starfields toward the center of the galaxy. In such fields, patterns emerge where the background star density drops to nearly zero — a "hole" in the sky. Holes in the sky don't exist, but thousands of background stars do exist, so something must be blocking light from those stars. The culprit? You guessed it — dark nebulae.

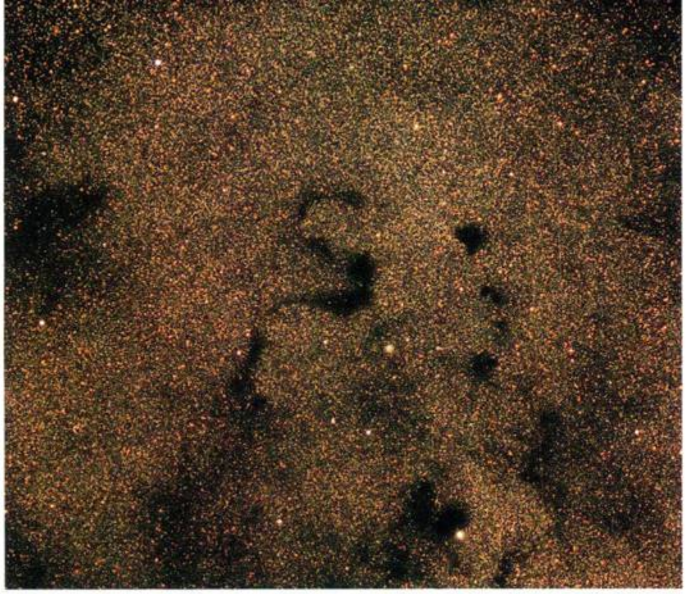
To say that observing dark nebulae is a challenge would be putting it mildly. To view a dark nebula you must observe something that is not there, or more properly something that is there but visible indirectly. Some dark nebulae are easier to see than others. The best type to start with are those that lie in front of extremely rich star fields — the greater the density of "missing" stars, the easier the dark nebula is to see. One such example is Barnard 86, one of an extensive catalog of dark nebulae compiled by the American astronomer Edward Emerson Barnard. B86 is both easy to find and easy to see. It lies in star-rich Sagittarius next to the bright open cluster NGC 6520. A low-power telescope trained on this field on a dark night will show both the star cluster and the adjacent dark nebula, an opaque "hole" with only a few foreground stars visible.

Other dark nebulae are far more challenging. The dark nebula catalogued as B72 and known as the Snake Nebula (or S Nebula) lies 1.5° northeast of the bright star Theta Ophiuchi. Its winding, S-shaped form can be discerned on the darkest of nights. In the winter sky you will find the most famous dark nebula, the Horsehead Nebula (B33) in Orion. Lying just south of the belt star Zeta Orionis, the nebula is a shadowy form visible against the faint outline of the emission nebula IC 433. The problem is not seeing the Horsehead, but the extremely faint emission nebula that backlights it. Use averted vision, moderately high power, and at least an 8-inch telescope to spot this legendary object.

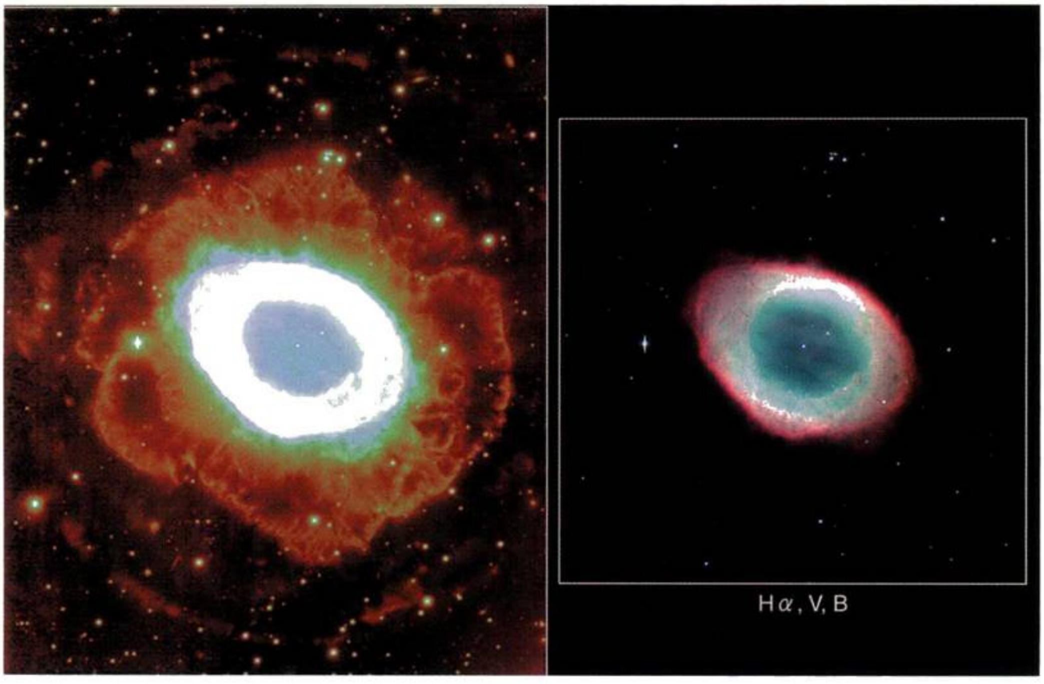
The varied forms of nebulae offer some of the most rewarding sights of the night sky. From naked-eye glows to objects that need help to stand out against the blackness of space, these cosmic clouds offer hundreds of beautiful sights for the small telescope user. Nebulae are the most challenging telescopic sights of any component of our galaxy. Only one realm of deep-sky objects demands and offers more for backyard astronomers — the realm of the galaxies.



THE CALIFORNIA NEBULA, in Perseus, appears magenta in this tricolor image taken by Chuck Vaughn. He used three filters: red, green, and blue, each with an exposure of 180 minutes on Kodak Tech Pan 2415 film. ▲ CHUCK VAUGHN



THE SNAKE, also known as Barnard 72, is a dark nebula slithering its way above the bright star 44 Ophiuchi [bottom center]. Michael Stecker captured this image using a 155mm f/7 EDF refractor and Pentax 6x7 camera. Two 50-minute exposures with unhypered Kodak Pro 400 PPF-120 film were combined to make the portrait. ▼ MICHAEL STECKER



THE RING NEBULA, M57, may resemble a planet when viewed through a small telescope, but in fact is the remains of a dying star. The right side image is a composite made from three separate images, each taken through a different filter. ◀ SUBARU TELESCOPE; NAOJ

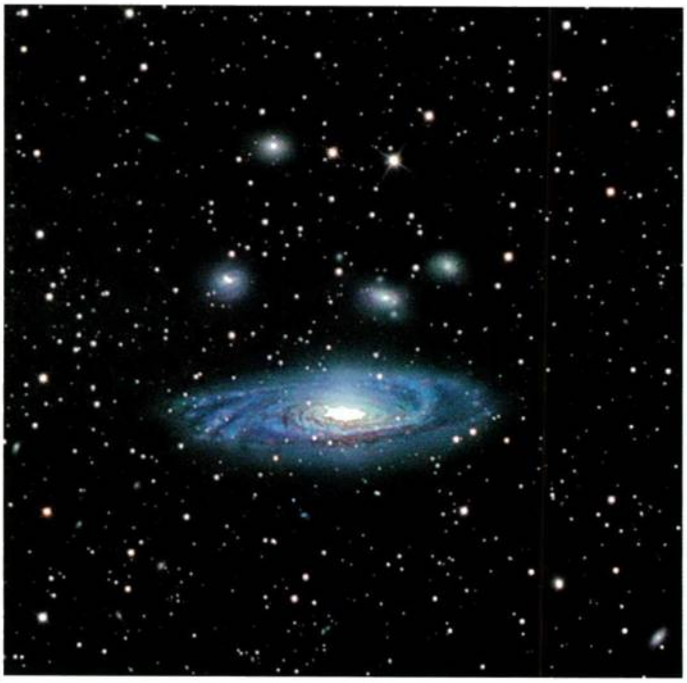
a universe of galaxies

Thus far everything we've surveyed has been a component of the Milky Way Galaxy. Yet the universe is composed of billions of separate galaxies, each an independent, "island" star system. In terms of astronomical history, galaxies are very new concepts. Throughout the hundreds of years of telescopic observation since 1610, astronomers observed many fuzzy patches in the sky, meticulously catalogued them, and labeled them "spiral nebulae." Yet they are completely different from nebulae, which, as we've seen, are gas clouds scattered throughout galaxies like our Milky Way. Although some of the fainter galaxies appear similar to nebulae in earthbound telescopes, they are enormously larger and incredibly more distant than anything we've surveyed thus far.

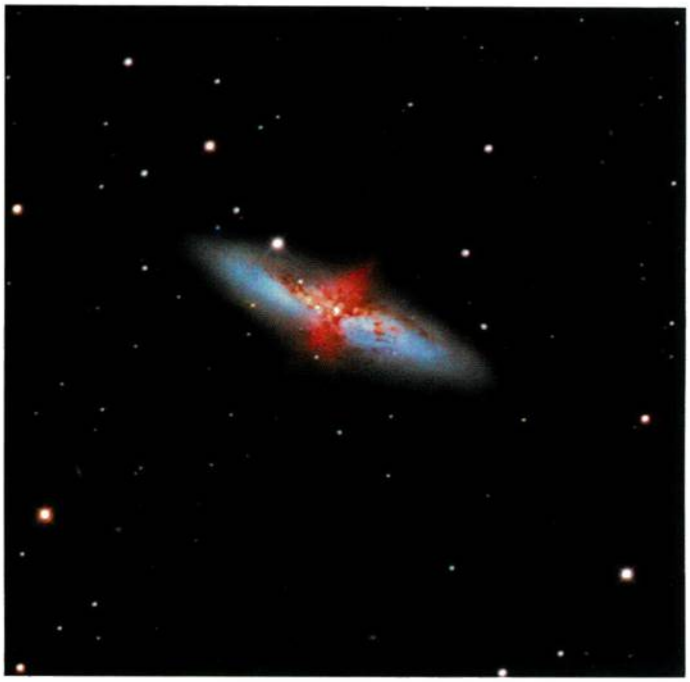
Galaxies remained a mystery until 1923, when the American astronomer Edwin Hubble demonstrated the true nature of these cosmic beasts. Hubble identified a group of variable stars called Cepheids in one of the brightest "spiral nebulae," the Andromeda Galaxy, M31. The behavior of these Cepheids was precisely known because of the hundreds previously discovered in our galaxy, yet Hubble found that Andromeda's Cepheids were dramatically fainter than those that lay nearby. Hubble used the 100-inch Hooker telescope at the Mount Wilson Observatory in the San Gabriel Mountains near Los Angeles. He discovered that spiral nebulae were actually huge systems of stars incredibly far away, and the term *galaxy* was born.

what makes a galaxy?

Galaxies come in a multitude of shapes, masses, and luminosities. The Milky Way, a rather ordinary spiral galaxy, measures about 100,000 light-years from end to end. Yet some galaxies — the giant ellipticals — can span 2 million light-years, while others — dwarf



MOTTLED GALAXY NGC 7331 ▼
shows off its well-defined spiral structure in a deep backyard exposure. Visible in the background are some of NGC 7331's companions and neighboring galaxies. This image was made using a 14.5-inch SCT with Kodak Royal Gold 200 film. TONY AND DAPHNE HALLAS



THE CIGAR GALAXY, M82, ◀
is a starburst galaxy shining brightly in infrared light and — along with M81 — provides a double-whammy for observers lurking in the vicinity of the Great Bear.
TONY AND DAPHNE HALLAS

SPIRAL GALAXY M81 can be easily found shining brightly in the northern constellation Ursa Major. Its grand spiral arms spread almost as wide as the Milky Way.

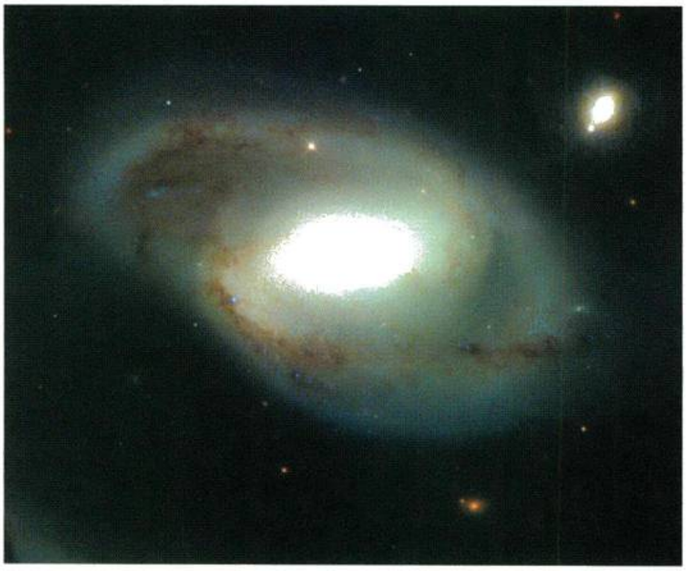
ROBERT GENDLER

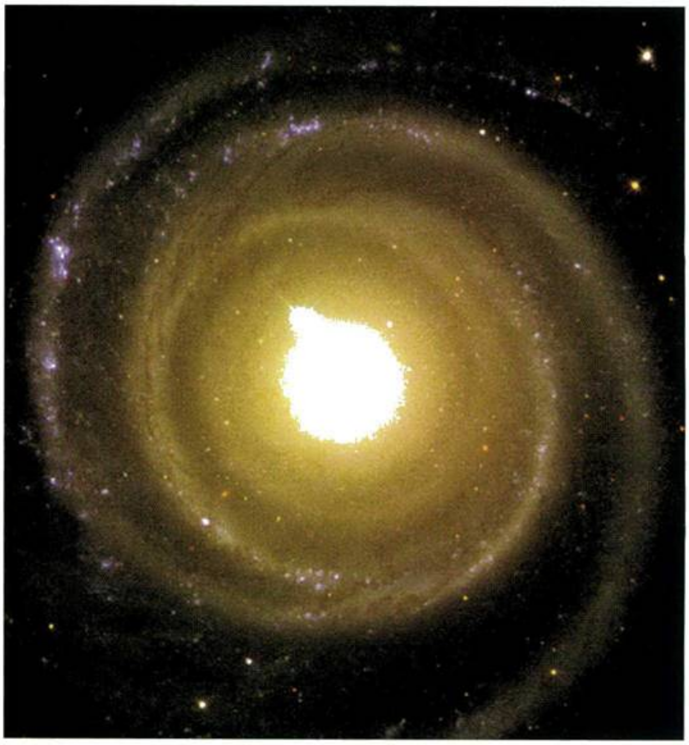
ellipticals — measure a relatively minute 10,000 light-years in diameter. A galaxy like ours contains about 200 billion stars. Its stellar population is dwarfed, however, by the trillions of stars in the largest giant ellipticals.

Generally, astronomers place galaxies into four broad classes. Spiral galaxies, of which our Milky Way and the Andromeda Galaxy are but two examples, consist of a dense nucleus and a spiral disk surrounded by a halo of gas and dust. Within the class of spiral galaxies, two subclasses exist: normal spirals and so-called barred spirals. Barred spirals contain a distinct bar-shaped central region, from which spiral arms emanate, but otherwise are similar to normal spirals.

Astronomers originally classified galaxies, including normal spirals (S) and barred spirals (SB) using a scheme devised by Hubble in the years following his discovery. The classifications Sa and SBa represented spirals and barred spirals with large centers and tightly wound spiral arms. Sb (and SBb) galaxies have smaller centers and spiral arms that are less tightly wound about the centers. Sc (and SBc) galaxies have tiny centers and large, patchy arms.

Elliptical galaxies are giant globes of stars and dust that lack the distinct disk shapes of spirals and seem to be organized only in the sense that they have concentrated nuclei. In the Hubble classification scheme, ellipticals are categorized from E0 to E7, with E0 representing a spherical galaxy and E7 an eccentric, oval object. Astronomers also recognize objects called lenticular galaxies that seem to consist of a spherical halo component like ellipticals yet contain a disk of stars as well.





NGC 4319 AND QUASAR MARKARIAN 205 (upper right) ▲ appear as friendly neighbors in this Hubble Space Telescope image but are actually separated by nearly a billion light-years. NGC 4319's outer arm waves toward the lower left of the image. NASA AND THE HUBBLE HERITAGE TEAM (STScI/AURA)

AT A DISTANCE OF 29 MILLION LIGHT-YEARS, NGC 4603 ◀ lies in the constellation Centaurus. The Hubble Space Telescope captured this stunning image of a relatively nearby cosmic neighbor. JEFFREY NEWMAN (UNIVERSITY OF CALIFORNIA AT BERKELEY) AND NASA

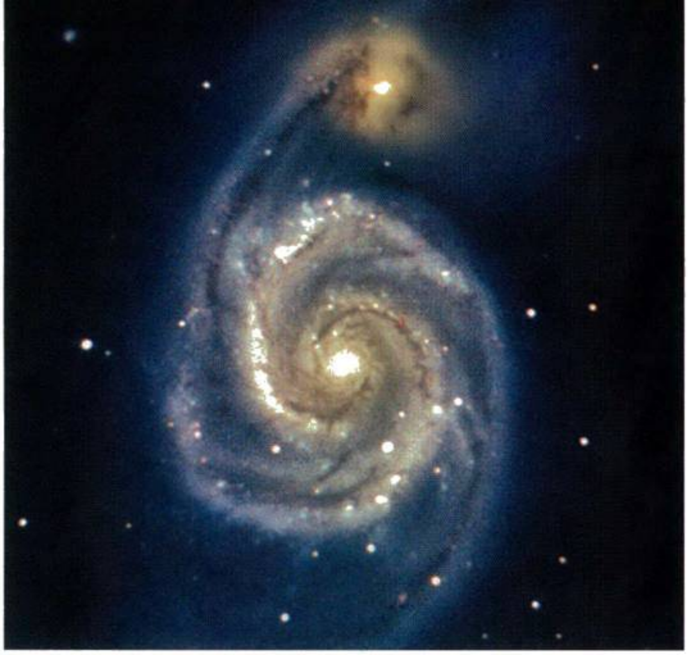
GALAXY NGC 4622 confuses ▶ astronomers by spinning in a clockwise direction. Rather than the spiral arms lagging behind the rotation of the galaxy, NGC 4622's arms lead the way as this bright spiral spins its way through space. NASA AND THE HUBBLE HERITAGE TEAM (STScI/AURA)

Irregular galaxies are just that — irregular, and composed chiefly of discrete patches of stars and gas clouds. Their lack of form makes them as individually varied as any type of object in the universe, and they were the original "trash can" category devised by Hubble to facilitate classifying galaxies that didn't fit into the spiral or elliptical classifications. Another type of oddball category, peculiar galaxies, consists of distorted, interacting, or otherwise traumatically affected citizens of the cosmos.

Today, astronomers use a new, more complex system of classifying galaxies that was devised by the astronomer Gerard de Vaucouleurs in 1959. De Vaucouleurs's classification system provides a better description of what a galaxy looks like. His approach, which used many more galaxies than Hubble's, better explains the specific details that have a bearing on the way galaxies of various types evolve.

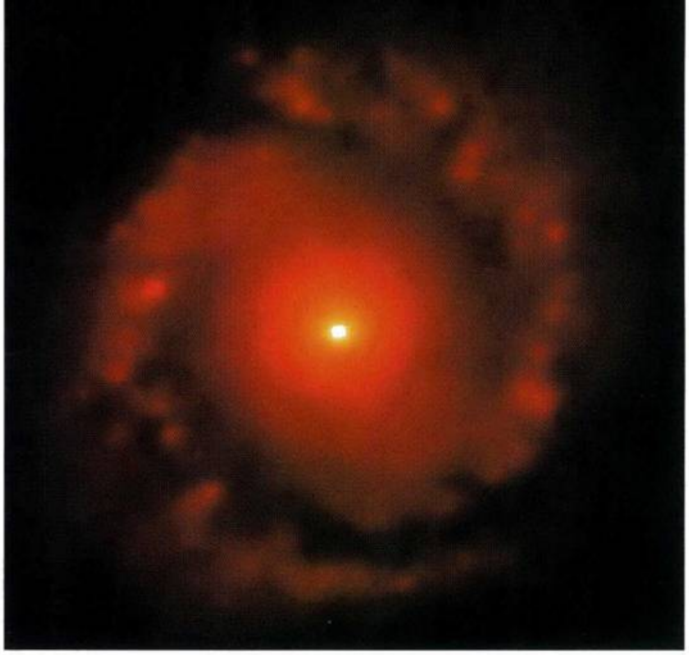
the local group of galaxies

Billions of galaxies are scattered throughout billions of light-years of the observable universe. Our little corner of the universe, however, constitutes what astronomers call the Local Group of galaxies. Contained within a sphere approximately three million light-years in diameter, the Local Group is our home base in the galactic universe. It consists of the Milky Way and its southern sky companion galaxies, the Large and Small Magellanic Clouds, the Andromeda Galaxy and its retinue of small companions, and about three dozen other galaxies — mostly dwarf ellipticals. Other notable members include the Pinwheel Galaxy (M33) in Triangulum, Barnard's Galaxy



THE WHIRLPOOL GALAXY, M51, ▼ appears to embrace its lesser companion, NGC 5195, in this image made by a Texas amateur astronomer. It constitutes one of the easiest interacting galaxies to see in backyard telescopes.

JASON WARE



AN ENERGETIC SEYFERT GALAXY, NGC 1097 ▲ shines forth in false color in a recent ground-based image. The shot was made with the Abu thermal infrared camera built by the National Optical Astronomy Observatory, on the Gemini South 8-meter telescope.

GEMINI OBSERVATORY/ABU TEAM/NOAO/AURA/NSF

(NGC 6822) in Sagittarius, Maffei 1 in Cassiopeia, the irregular galaxy IC 1613 in Sextans, and the dwarf galaxies in Fornax, Draco, Sculptor, Sextans, and Pegasus.

The most magnificent of the local galaxies is the Andromeda Galaxy, the sister spiral to our own. The Andromeda Galaxy is considerably larger than the Milky Way, and it is the brightest galaxy visible to the naked eye from the Northern Hemisphere. Consult a star chart, go outside on a dark night, and look toward the right spot in Andromeda. You'll see the galaxy as a fuzzy, elongated patch of milky light. This galaxy is the most distant object visible to human eyes, lying approximately 2.9 million light-years away. It's a humbling thought to see the faint glow from this object and know that the photons passing into your eye began their journey through space as primitive mammals struggled to conquer the vast domain of Earth.

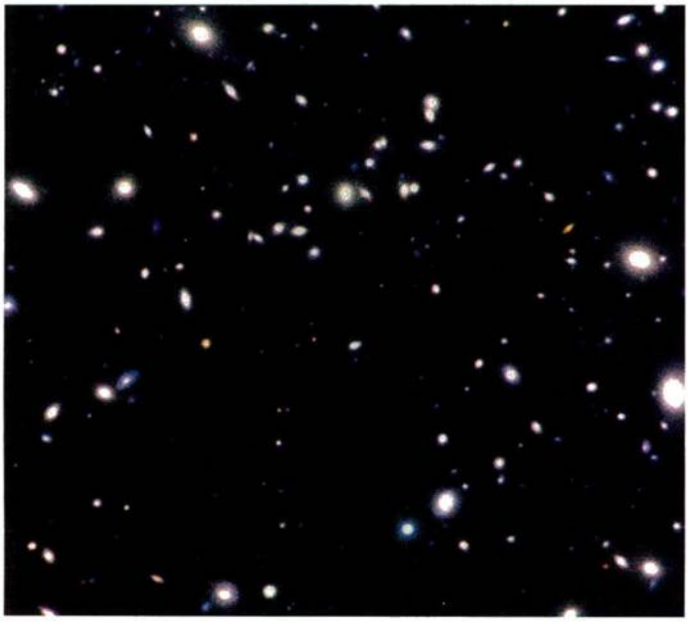
galaxy groups and clusters

Just as our Milky Way belongs to a galaxy group, so do other galaxies. In fact on a larger scale galaxies exist in giant clusters and superclusters, and the wholesale structure of the universe at large is hardly homogeneous when viewed with backyard telescopes. As you begin to observe galaxies you'll note that they are not uniformly distributed across the sky. Part of this is due to the fact that dust in the plane of the Milky Way blocks light from galaxies beyond. However, the great windows into the deep universe visible in the spring and autumn evening skies demonstrate the clumping effect of galaxies near and far.

The greatest cluster of galaxies near us is the Virgo Cluster, visible as a collection of dozens of faint galaxies scattered over the constellations Virgo and Coma Berenices. Its most prominent members are M84, M86, and M87. Other outstanding and observable examples of galaxy clusters lie in the constellations Coma Berenices, Hercules, Fornax, Sculptor, and Perseus. Most galaxy groups and clusters visible in backyard telescopes lie tens of millions or even hundreds of millions of light-years away. The fact that we can see individual galaxies at such distances testifies to the immense energy output of these distant monsters of the deep.

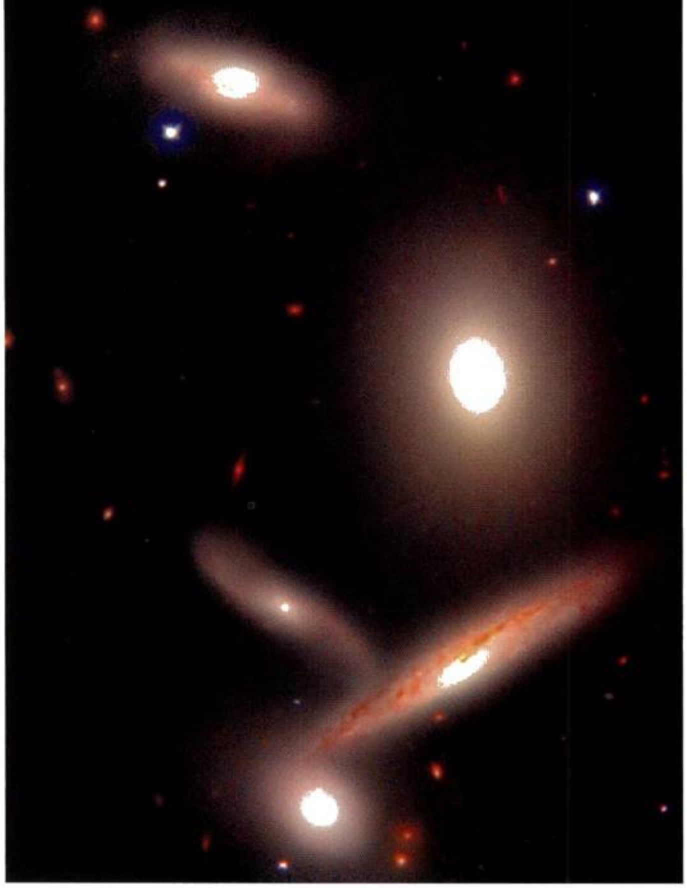
observational tips for galaxy watchers

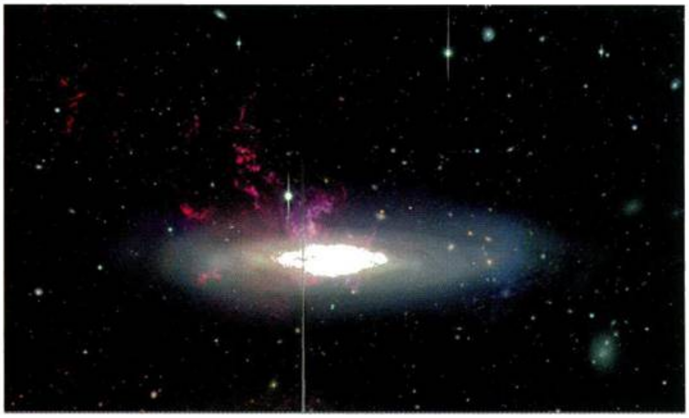
A medium-sized telescope is capable of showing thousands of galaxies. To see the most detail possible, however, you must observe from a dark sky site and without the Moon in the sky. Take along a dim red flashlight so you will not disturb your dark adaptation; this is your eyes' sensitivity to the galaxies' faint light. Make sure you have a star atlas sufficiently



GALAXY CLUSTER ABELL 851 ◄ makes its residence five billion light-years from Earth. Almost every object in this image is a galaxy. The blue galaxies that speckle this image are protogalaxies found only in distant clusters.

SUBARU TELESCOPE/NAOJ





A CELESTIAL TANGO, Hickson ▲ Compact Group 40 contains five galaxies. Many galaxies in the universe live in small groups like this one, which contains (top to bottom) a spiral, an elliptical, two more spirals, and a lenticular. SUBARU TELESCOPE/NAOJ

VIRGO CLUSTER GALAXY NGC 4388, ◀ imaged with the Suprime-Cam on the Subaru Telescope, reveals long filaments of ionized hydrogen gas extending 110,000 light-years above the disk of the galaxy. Such observations help astronomers understand the evolution of galaxies inside dense galaxy clusters. SUBARU TELESCOPE/NAOJ

THE HIGHLY-INCLINED SPIRAL NGC 253 ▶ in Sculptor offers bright details to observers who are fortunate to see it high in the sky. Jason Ware shot this image with a 16-inch Meade SCT at f/10, Fuji HG 400 film, and a composite of two 60-minute exposures. JASON WARE

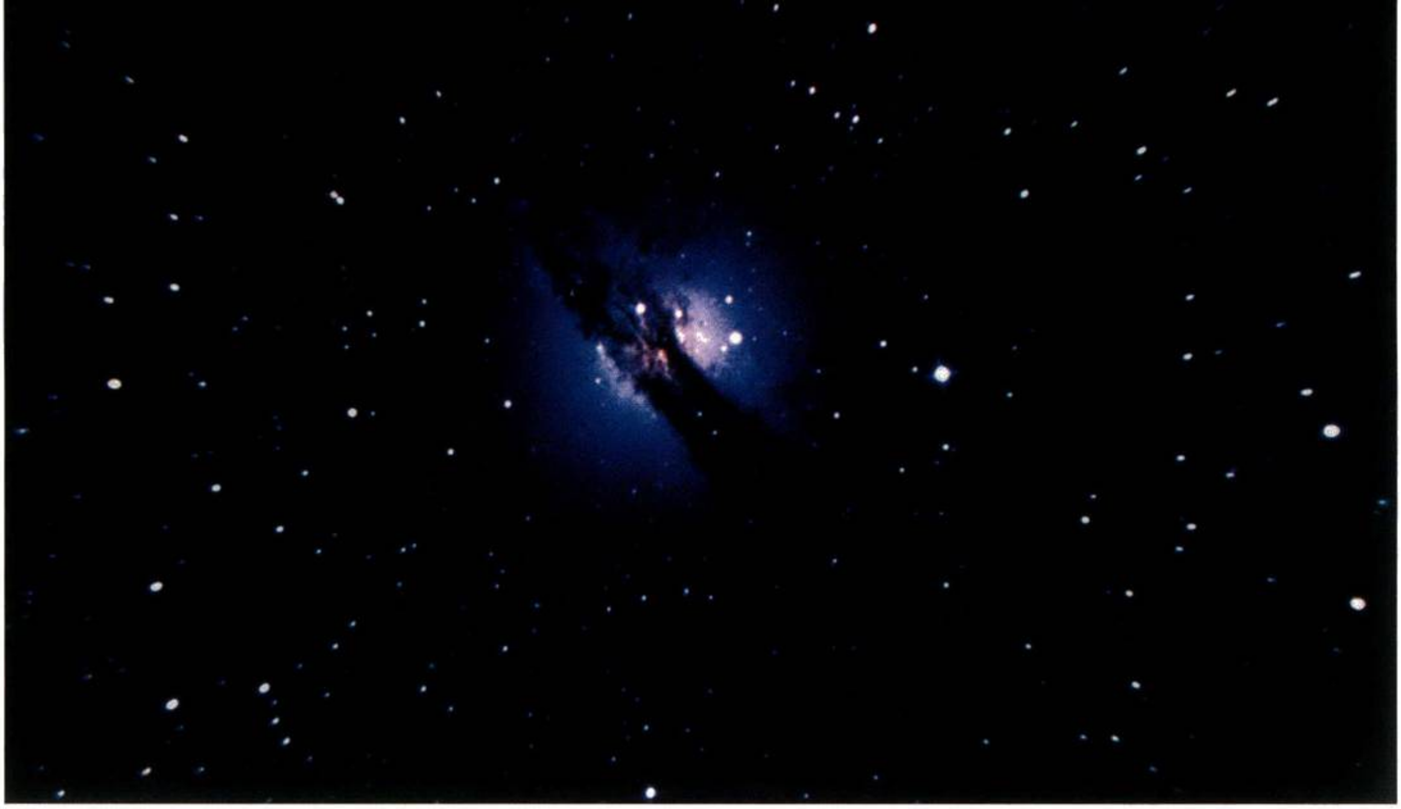
detailed to observe both bright and faint galaxies. If you wish, keep a written journal of your observations or sketch what you see at the eyepiece.

Locate the galaxy you want to observe by star hopping, correlating the stars on your atlas to those you see in the sky. To find the galaxy, use a low-power eyepiece. When you center it in the field, study the galaxy and be sure to use averted vision — glancing to the side of the field. This utilizes your eyes' rods, its faint light detectors. As you look at the galaxy, make notes — mental or otherwise — on the galaxy's appearance. Is the center condensed and very bright? Can you see a faint halo of light surrounding the galaxy's center? Is spiral structure visible? Do you see other deep-sky objects in the field of view? After you've viewed the galaxy at low power, switch to a higher magnification and see if more detail becomes visible. Before you know it, you'll be a seasoned galaxy watcher.

Several galaxies are not only observable with small telescopes, they also show a reasonable amount of detail under dark skies. For Northern Hemisphere viewers, the Andromeda Galaxy and M33 are favorites. For Southern Hemisphere observers, the Magellanic Clouds offer unrivaled detail because these two Milky Way satellites lie relatively close to our own galaxy.

Other galaxies worthy of early and detailed inspection include the big spiral NGC 253 in Sculptor, Centaurus A (NGC 5128) in Centaurus, the galaxy pair M81 and M82 in Ursa Major, the edge-on galaxy NGC 4565 in Coma Berenices, the Whirlpool Galaxy (M51) in Canes Venatici, M101 in Ursa Major, the Sombrero Galaxy (M104) in Virgo, NGC 7331 in Pegasus, and M83 in Hydra.

Centaurus A is a particularly outstanding object for amateurs to observe because it is so bright, large, and unbelievably weird.



Although it has a far southern declination (and so is visible in the United States only from the southernmost states), it is well worth viewing if practicable. Carrying the number 5128 in the *New General Catalogue*, the galaxy picked up the alternate name Centaurus A because it is a strong emitter of radio energy. (The galaxy is also a powerful producer of X-ray and infrared emission.) Centaurus A's oddball structure, visible even in small scopes, demonstrates that something awfully peculiar is going on inside it. In the eyepiece, Centaurus A appears as a glowing ball of light measuring some 18.2' by 14.5' in extent — nearly one-quarter the size of the Full Moon. The galaxy glows at magnitude 7.0, making it invisible to the unaided eye but visible as a smudge in binoculars.

In telescopes you'll see what appears to be a black band crossing the center of Centaurus A, causing it to appear bisected. This in fact is a broad dust lane that encircles the galaxy and passes in front of the nucleus. High powers with amateur telescopes 12 inches and larger in aperture reveal faint glows within this dark dust band. Astronomers have long studied this galaxy as one of the most peculiar star systems known. It seems clear that because of its tremendous energy output, Centaurus A is home to a highly energetic supermassive black hole that resides deep within the galaxy's nucleus.

quasars

Galaxies have mysterious and extraordinarily distant cousins called quasars, an abbreviated name for quasi-stellar objects. Lying billions of light-years away, quasars are the energetic centers of extremely young galaxies. We see these powerful young objects because the farther we look back in space, the farther we are looking back in time. To see a quasar is to see a galaxy in its youthful chaos shortly after formation. To see an object at such a large distance, it must be incredibly bright. The energy output of a quasar exceeds that of anything else in the universe, and astronomers believe that supermassive black holes lie deep inside these objects and power them like central engines.

A few dozen quasars are visible in backyard telescopes, but because of their great distance they appear as faint stars. The brightest quasar is 3C 273, located in the constellation Virgo. This object glows feebly at magnitude 12 and is slightly variable in light output. Quasars are to deep-sky objects what Pluto is to the solar system — a joy to spot for the sheer mental euphoria of having looked across the universe.

EXPLODING GALAXY CENTAURUS A ▲ is one of the oddest looking galaxies in the sky — the result of two galaxies colliding long ago. Jack Marling made this shot with a 24-inch scope at f/7.5, ISO 100 film, and a 50-minute exposure.

JACK MARLING

SPIRAL GALAXY M81 in Ursa ◄ Major is one of the brightest galaxies in the northern sky. Its delicate spiral arms are visible in an 8-inch scope on a dark night.

TONY AND DAPHNE HALLAS

where is amateur astronomy going?

As a practice, amateur astronomy is in its infancy. Although beings have undoubtedly looked skyward for millions of years, the advent of the telescope for astronomical purposes was begun less than 400 years ago. The instrument crucial to detailed astronomical observing remained firmly in the hands of scientists until quite recently. Amateur astronomy would not rise up as a movement in the United States until a rather peculiar period for societal functions — the Civil War. In 1862, as McClellan's army slowly tramped toward Richmond, a small group of interested persons formed the Chicago Astronomical Society. It is the oldest such group in the U.S., and it began a movement that has seen hundreds of astronomy societies come and go. Today some 250 astronomical societies exist in the U.S. and Canada, forming the backbone of a bustling community of enthusiasts who actively observe, study, and think about the universe.

Amateur astronomy got such a slow start substantially because of the difficulty of obtaining telescopes. In fact, before the production of huge quantities of optics during World War II, amateur astronomers had to make their own optics for telescopes. As far back as the 1920s, astronomers and enthusiasts like Russell Porter and Albert G. Ingalls promoted telescope making in publications such as *Scientific American*. However, unless amateur astronomers first became amateur telescope makers, they were excluded from easily observing the universe. This began to change by the middle of the century. Availability of surplus optics following World War II and a burgeoning telescope industry spurred by the advent of the "space age" resulted in more affordable and easier-to-use telescopes by the 1960s. Today, telescopes are better and more easily obtained than ever, and the telescope industry deserves a great salute for their efforts to produce a quality product at a reasonable price. After all, most scientific instruments are fantastically more expensive than telescopes.

enjoying astronomy in the 21st century

Amateur astronomy has never been so well off. This is most easily documented by the record activity at all levels of amateur astronomy. Subscriptions to magazines are higher than they've ever been, attendance at star parties is higher than ever before, memberships in astronomy clubs are greater than any time in the past, and the amount and sophistication of what amateurs are observing is rapidly increasing. Professional astronomy, too, looks forward to a bright future. A repaired Hubble Space Telescope, many new, large ground-based instruments, sophisticated techniques like adaptive optics, and further exploration of the solar system all guarantee that the years ahead will be very exciting.

All this adds up to a bright future for the hobby of astronomy as we enter the 21st century.

THE GRANDEUR AND BEAUTY of deep space are revealed in this mosaic of the Orion Nebula, M42, and its surrounding cousins — M43 and NGC 1973–5–7. The image reveals in phenomenal detail areas of both glowing gas clouds and swaths of dust reflecting starlight toward us. ROB GENDLER

A MOONLIT SUMMER NIGHT in the High Sierra backcountry is a joy to experience. Amateur astronomy offers getting in tune with nature, as campers enjoy both celestial and terrestrial surroundings. Chris Cook used a Nikon 24mm f/4 lens and Kodak Gold 100 film for this 60-second exposure. CHRIS COOK

where does it go from here?

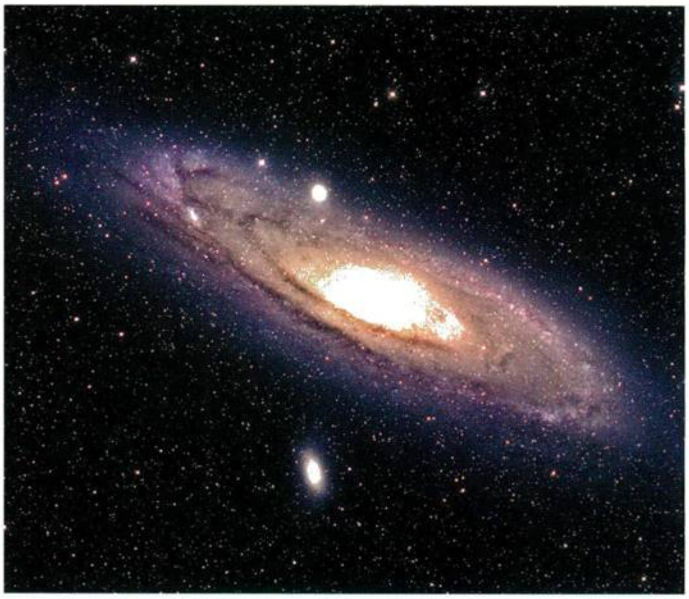
To understand where amateur astronomy is going, we should try to understand why people are interested in astronomy in the first place. I asked this and other questions of several dozen amateur astronomers in 1990, seeking to find out what originally attracted these people to amateur astronomy and where they think the hobby is headed. The results, sampled below, paint a clear picture of the hobby itself.

Why become an amateur astronomer? The reasons are as individual as the people who answered. "I regularly stopped to look for Venus each night as a five year old," says Klaus R. Brasch, a skilled astrophotographer living in San Bernardino, California. "My mother scurried me off to shelter during Allied bombing raids over Germany during the twilight of World War II," he says. But astronomy really took hold of Brasch when as a teenager he lived in Canada. "When I turned 15 my father gave me a 2-inch telescope and the first time I observed Saturn I was hooked." Likewise, Nottingham, England's Alan Heath became interested in astronomy while watching stars over England during the World War II blackouts. In strikingly similar fashion, Ron Arbour of Hants, England, first tasted astronomy while staying with his grandmother in Winchester, England. "I may be the youngest ever to have taken an active interest in astronomy," reports Arbour. "It was during World War II that I hid under a table as a two-year-old while a dogfight occurred overhead. Afterward, grandmother showed me the stars in the sky to prove that everything was all right."

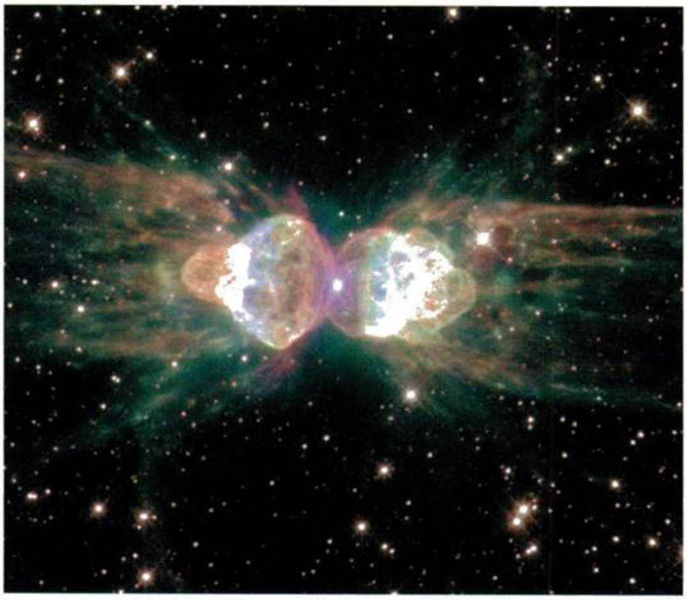
According to Jim Phillips of Charleston, South Carolina, "amateur astronomy provides hours of fun, adventure, and mental stimulation." Phillips has long been active in the Association of Lunar and Planetary Observers, a national group. He is known primarily for extraordinary pencil renderings of the Moon and planets. Phillips is cautious about analyzing his interest, however, and quotes the American writer Paul Hendrickson: "If a person spends too much time trying to define a passion in life, the passion is liable to vanish on him."

The talented eclipse photographer Jacques Guertin, a resident of Newark, California, attributes his passion for astronomy to an appetite for reading. "I always admired the photographs of space I saw in books, and thought to myself that I would really like to

A DEEP VIEW OF THE UNIVERSE ► reveals a colorful array of galaxies as seen in visible and infrared light by NASA's Hubble Space Telescope. Hubble's sharp vision recorded galaxies fainter than 28th magnitude in this shot. R. WILLIAMS (STSCI), THE HDF-SOUTH TEAM, AND NASA



THE ANDROMEDA GALAXY, M31, ◄ is the nearest spiral galaxy to our own, the Milky Way. Bright enough to be observed with the naked eye, it was noticed and written about as early as 905 A.D. by Persian astronomers. JASON WARE



A STUNNING IMAGE OF MENZEL 3, ▲ also known as the Ant Nebula, taken with the Hubble Space telescope, challenges long-held ideas about the final stages of the lives of stars. By studying planetary nebulae like Mz 3, astronomers are getting a clear picture of the Sun's fate. HUBBLE HERITAGE TEAM (NASA/STScI/AURA)

take some of my own." Guertin is not alone in that regard. Robert Reeves of San Antonio, Texas, witnessed a lunar eclipse from Miami, Florida, in 1960. Before seeing the eclipse he was inspired to produce his own photo of the event like the one in his seventh-grade science textbook. A similar event happened to Michael Covington of Athens, Georgia, author of an important and widely-read book on astrophotography. "I read ahead in my sixth-grade textbook and found the astronomy section fascinating," he recalls, adding that "my teacher loaned me an old college textbook that provided enough depth to sustain my interest."

The accomplished French astrophotographer Jean Dragesco discovered two "opposite worlds," astronomy and microscopy, at age 15 in 1935. Both activities required good lenses, and he soon found himself experimenting with microscopes and telescopes. What followed from tinkering with various lenses was one of the greatest

MARKARIAN'S CHAIN in the Virgo ▲ Cluster of galaxies was captured using an 155mm f/7 EDF refractor and hypersensitized Kodak Pro 400 PPF film. Two 50-minute exposures were stacked to create this image. MICHAEL STECKER

THE LARGE MAGELLANIC CLOUD ▼ is a satellite galaxy of the Milky Way and is so bright it can be seen with the naked eye from the Southern Hemisphere. In 1987 a supernova erupted in the galaxy, giving astronomers their best look at an exploding star. NOAO/AURA/NSF

THE GAMMA CYGNI NEBULA ◀ shows off its crimson in this photograph made by an advanced backyard astrophotographer. Chuck Vaughn used a 130mm f/8 refractor and shot the image on Kodak Technical Pan 2415 film, later making a color composite. CHUCK VAUGHN

careers in astrophotography the world has known.

Other astrophotographers fell into recording the sky on film through less straightforward means. "I was always influenced by seeing the work of the great astrophotographers of the 1950s," says John P. Gleason, a neighbor of Guertin's in Newark.

"But it was really the advent of the Schmidt-Cassegrain telescope in the '70s that made astrophotography seem so perfectly natural — it was an entirely new concept that beautifully facilitated shooting the sky," he says. For Preston Scott Justis of Virginia Beach, Virginia, it was the Apollo space program that started his lifelong pursuit of astrophotography.

Astrophotographers constitute only half of the story, however. Those fueled with the passion of simply observing the sky, of going after the legendary objects that shouldn't be visible, of capturing on paper the subtle shades of the telescopic view, abound. Dave Kriege of Lake Mills, Wisconsin, manufacturer of Obsession Telescopes, had his first taste of the business when his father helped him build a 4-inch reflector for an eighth-grade science project. Like thousands of others, Jim Barclay of Queensland, Australia, found himself caught up in the excitement of trying to spot Sputnik 1 as it passed overhead in 1957. He observed it successfully and tried to photograph the satellite as well, but the first roll of film was fogged. "Son, if you want to photograph anything at night, you've got to use a flashbulb." Despite that bit of misguided advice at a photo store, Barclay embarked on a career of observing and photography.

Edmonton, Alberta, amateur Alister Ling is an enthusiastic patron of amateur astronomy. "The feelings I get from participating in astronomy range from pleasure and relaxation to a full blown rush," he says. "Some of the events that defy emotional description are a total solar eclipse, a full-sky display of aurorae, watching a star pop in and out of view while passing behind Saturn's rings, and the swirling

SPACE SHUTTLE ENDEAVOUR streaks overhead amid the stars of Orion and Gemini in this image taken in 2000. In 2003, following the Columbia tragedy, NASA's direction for the manned space program remains murky.

JEFFREY PETTITT

beauty of the Orion Nebula viewed with a large telescope under a dark sky."

For many amateur astronomers the drive to observe the heavens derives from a natural curiosity — a big part of the human spirit. Glenn F. Chaple, Jr., of Townsend, Massachusetts, loved exploring things as a child. "I cajoled my parents into buying a tiny, tabletop refractor," Chaple recalls. "What an incredible sight the rugged, cratered surface of the Moon turned out to be!" But Chaple, like many children, soon lost the passion when he found locating stars and galaxies difficult. "My interest rekindled during high school," Chaple says. "I had my first real stargazing session and I've never lost the exhilaration of observing the universe since that night." Swanton, Maryland, amateur astronomer Gus E. Johnson, discoverer of an extragalactic supernova, frankly states, "I don't know where I got the interest originally, but it lay dormant for years until high school when it caught like fire." Similarly, Australian amateur Gordon Garradd says "I can't really trace an astronomy interest to one particular time or event." A fellow Australian, Gerd Bahr-Vollrath, discovered astronomy after moving from "frosty, cloudy Europe" to "dark, warm, clear Australia." Chris Schur's observing interests expanded when he moved from Michigan to Arizona and found clear skies.

Eclipse chaser Joel K. Harris of Burbank, California, recalls seeing a single illustration in an early textbook that was "emblazoned" on his mind. "I was seven years old at the time," Harris recalls, "and I think the illustration of people watching an eclipse struck my subconscious mind. I determined right then that some day I would stand under the shadow of the Moon and watch an eclipse for myself." Ronald E. Royer of Lakewood, California, remembers watching a comet in 1946 and making a sketch of it, which started his lifelong interest. In the 1960s, comet hunter Alan Hale received some books on astronomy from his father. Amateur astronomer Dick Suiter attributes his interest to growing up in a small town, Hillsboro, Ohio. "Had I been a big city boy, I probably wouldn't have encountered astronomy," he says. "But I was born in the deep darkness of 1950s southern Ohio." In similar fashion, Peter F. Williams of Heathcote, New South Wales,

BRILLIANT AURORAL RAYS sparkle over the Alaskan frontier in an image recorded on March 13, 1982. Forrest Baldwin used a 50mm lens at f/1.4, Ektachrome 400 film, and a 6-second exposure. FORREST BALDWIN

recalls a vivid country sky as a child. "I remember seeing Orion in a crystal clear sky and being intrigued by the naked eye doubles Mu Scorpii and Alpha Capricorni," Williams says.

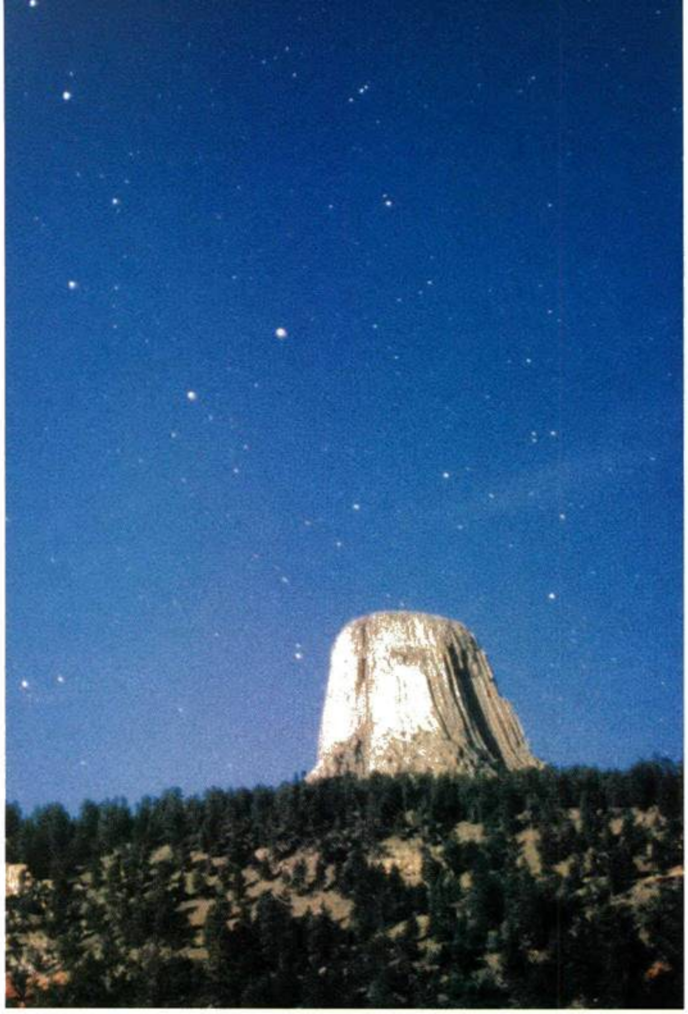
The active observer Susan C. French of Scotia, New York, fixed on astronomy as recreation while caring for her young son. "Reading was the only way at that time I could escape the house," says French, "and I found some old physics texts that led me to take a course in college. That led to a major interest in the stars."

the future of amateur astronomy

Where do these once-fascinated children feel amateur astronomy is heading? What will backyard skygazing be like in fifty years? The answers cover a spectrum.

English amateur Philip M. Bagnall thinks "the most likely change we'll see over the next fifty years is that amateur and professional astronomers will cooperate more, and so will amateur astronomers living in different countries." The skilled astrophotographers Bob Provin and Brad Wallis, Los Angeles amateurs, are concerned over the disappearing darkness of the night sky. Says Wallis: "We may have to start migrating farther from the overgrown metropolis in order to find a sky suitable for astronomy. I remember in the 1960s when we had to use flashlights at our observing sites in order to walk around. Now the sky is bright enough so that flashlights aren't needed." Columbus, Ohio, amateur Tom Burns also worries about the future of the night sky. "I hope that we're not witnessing a generation of children who will always look down at the concrete rather than up at the stars," he says. Chris Schur laments that "truly dark skies are getting harder to find even in Arizona today, and I shudder to think of the light pollution fifty years down the road." Gerd Bahr-Vollrath suggests that amateurs begin lobbying national political groups to create "dark-sky national parks, to preserve the night sky just as we need to preserve other natural wonders."

The Canadian astrophotographer Jack Newton is slightly more optimistic about the hobby. "I see a great future for amateur astronomy in general and for astrophotography in particular," he says. "I'm in the early stages of working with CCDs, which will revolutionize the ways backyard astronomers



THE BIG DIPPER WHEELS over Devil's Tower in Wyoming in this portrait shot with a 24mm lens at f/1.4, Ektachrome P800/1600 film at ISO 1600, and a 50-second exposure. JERRY SCHAD

THE SUMMER MILKY WAY gleams in this 10-minute exposure shot over the Arizona desert. Michael Terenzoni used a 16mm lens aimed south-southeast. MICHAEL TERENZONI

COLORFUL STARS TRAIL over the mountains of California in this striking image recorded by Jerry Schad. The photographer used a 35mm lens at f/5.6, Fuji 400 film, and a 5-hour exposure. JERRY SCHAD

image the cosmos." New York amateur Phil Harrington also sees a bright future: "Amateur astronomers are rediscovering the magnificent image quality of refractors," says Harrington. "This reawakening, coupled with the technology of improved eyepieces, computers, drive systems, and CCDs, will make amateur astronomy increasingly popular in the decades to come."

Atascadero, California, astrophotographer Lee C. Coombs is certainly up on the hobby's future. "New trends are continually surfacing and are evident at gatherings like Riverside, the Texas Star Party, and Stellafane," remarks Coombs. "Much of this is computer gadgetry that makes the hobby exciting, but it can't replace the solid core of amateurs who prefer to learn the sky by the seat of their pants." Coombs is hardly alone is thinking techno-hardware will take the art out of backyard astronomy. But Detroit area amateur Bryan P. Shumaker is not concerned. Says Shumaker: "It will certainly be effortless in the future to find any object an observer wants to locate. But I don't think this will hurt the art of observing any more than when in the auto industry electric car starters replaced hand cranks." Moreover, Alister Ling predicts: "As we move into an era of high-tech astronomy, pure visual observing will stand out proudly. Nothing strikes to the heart of one's soul as a real image, viewed live, and processed only by the most sophisticated of all computer imaging systems — eyes and brain."

Richard Baum, an experienced planetary observer living in Chester, England, sees things a different way. "I don't think amateur astronomy will or can change in any great way," Baum asserts. "People will be attracted and will look through telescopes. Some will be satisfied at a few looks; others will be hooked for life. Some observers and astrophotographers will equip themselves with sophisticated electronics and increasingly complex technology, but in the end it is the single individual's mind that either makes a great contribution or doesn't. The individual is the key, and people will always be people."

"Our children are the key to the future of astronomy, just as with any field of endeavor," warns Preston Justis. "I've watched my children's eyes light up as I've shown them views of celestial objects through the telescope. Our children's education in the sciences must not be compromised, for the sake of everything. Indeed, what could the next fifty years hold for us if ignorance were allowed to prevail?"

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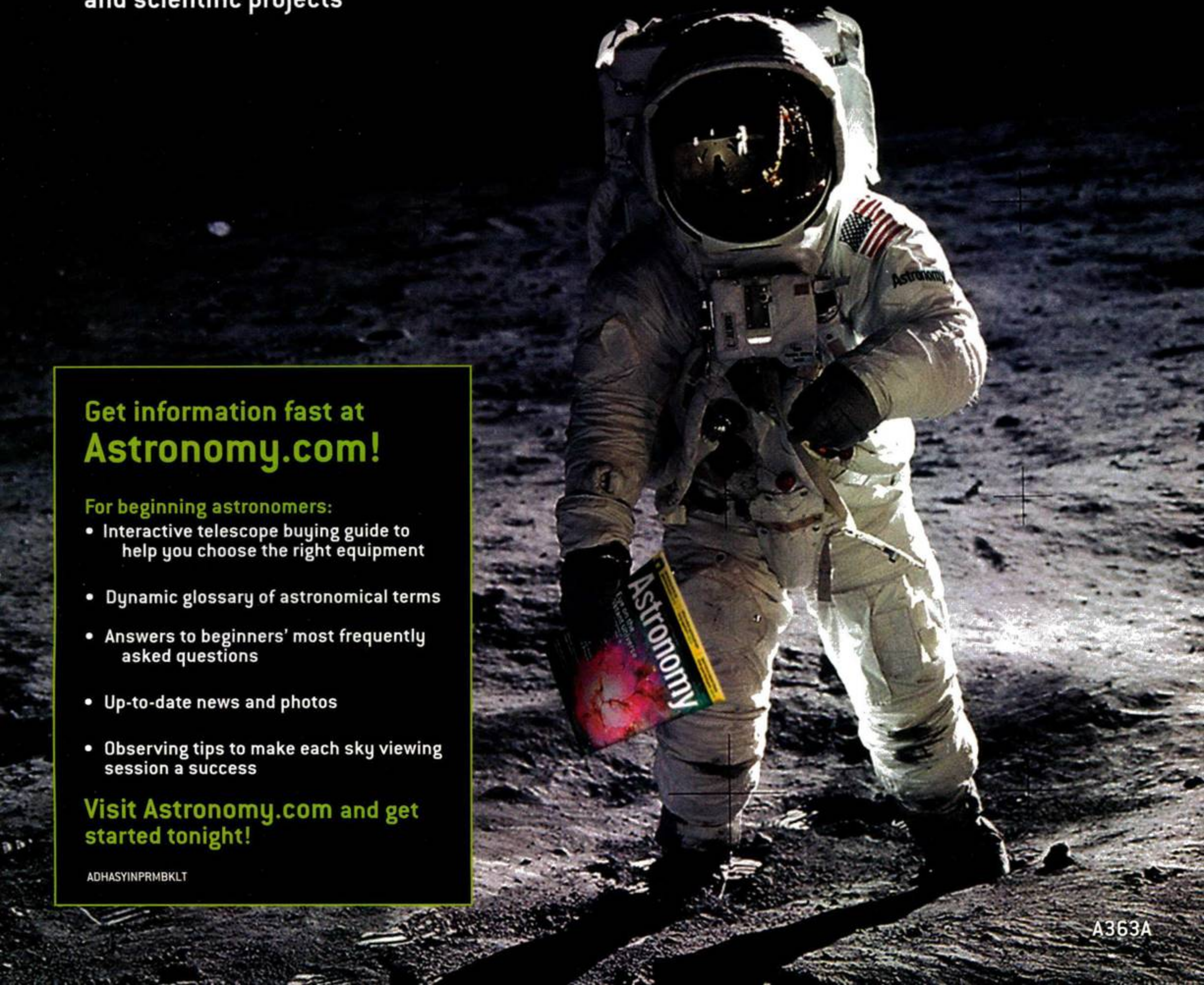

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